GEOLOGICAL SURVEY OF THE UNITED KINGDOM

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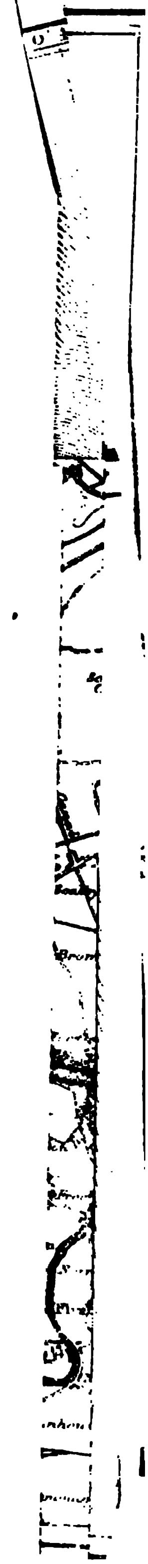

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MEMOIRS OF THE GEOLOGICAL SURVEY

OF THE

UNITED KINGDOM.

THE

JURASSIC ROCKS

OF

BRITAIN.

VOL. I.

YORKSHIRE.

BY

C. FOX-STRANGWAYS, F.G.S.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HER MAJESTY'S TREASURY.

LONDON:
PRINTED FOR HER MAJESTY'S STATIONERY OFFICE
BY EYRE AND SPOTTISWOODE,
PRINTERS TO THE QUEEN'S MOST EXCELLENT MAJESTY.

And to be purchased, either directly or through any Bookseller from
EYRE AND SPOTTISWOODE, EAST HARDING STREET, FLEET STREET, E.C., or
JOHN MENZIES & Co., 12, HANOVER STREET, EDINBURGH, and
90, WEST NILE STREET, GLASGOW; or
HODGES, FIGGIS, & Co., LIMITED, 104, GRAFTON STREET, DUBLIN.

1892.

Price Eight Shillings and Sixpence.

PREFACE.

WHEN the practice was introduced by Sir Roderick Murchison of publishing a descriptive text with each Sheet or Quarter-sheet of the Geological Survey, it was intended that these separate Explanations should be collated and condensed into Generalized Memoirs of each important geological district or formation. From time to time various Memoirs of this nature have been issued, and the time at length has arrived when, on the completion of the one-inch Map, it is possible to undertake the preparation of a series of Memoirs, combining the general results of the labours of the Survey, and presenting a compendious account of each of the geological formations of the country.

The task of writing a Memoir or Monograph on the Jurassic Rocks of the British Isles was entrusted to Mr. H. B. Woodward and Mr. C. Fox-Strangways. To the former member of the staff was allotted the description of the broad belt of Jurassic formations extending from the Humber to the Coast of Dorset with other outlying districts; while to his colleague was assigned the well-defined Jurassic area of Yorkshire, of which he had himself surveyed the greater part.

The present instalment of the general Monograph on the British Jurassic Rocks is devoted to the Yorkshire region, and has been prepared by Mr. Fox-Strangways. It does not profess to be itself an original research, but rather to present a general view of the work done, not only by the Geological Survey but by other observers among the Jurassic rocks of Yorkshire. Most of the details have already appeared, but it is confidently hoped that the rearrangement of them in a more comprehensive work, having regard to broad stratigraphical questions rather than to local variations, will be found to give them new interest as well as value to the geological inquirer. A good deal of new material, however, will be found in Chapters I., XVI.—XIX., the sixteenth and following chapter containing the Author's own views on the subjects discussed in the volume.

In a work ranging over so large a series of formations and so wide and varied a region it is hardly possible to single out special features for the attention of the reader. He cannot fail however to be interested in the remarkably clear natural sections in which the general geological succession is revealed, in the estuarine character of the Lower Oolite, in the fine development of the Corallian Series, and in the unique exposure of the remarkable group of strata which in the north-east of England connects the Jurassic and Cretaceous systems. If he is disposed to prolong his inquiry into younger formations and features he will be struck with the manner in which the disposition of the Glacial

Drift often conceals an older topography than that which the surface now presents, and with the singularly impressive connexion between the arrangement of the Jurassic rocks and the shapes of the hills and valleys that have been carved out of them.

It has been found necessary to divide the present portion of the Jurassic Monograph into two volumes. The first of these contains the general description of the formations. The second is devoted to a Catalogue of the Jurassic Fossils of Yorkshire—a work to which Mr. Fox-Strangways has devoted much time and labour for many years past, and in the final preparation of which he has been greatly assisted by his colleagues. It is hoped that this Catalogue will prove a useful guide to those who wish to study the various sub-divisions of the Jurassic Rocks of the north-east of England.

A copious bibliography has been compiled, but to avoid repetition it has been combined with that portion of the Jurassic Monograph in course of preparation by Mr. Woodward, and will appear in a subsequent volume. References to the more important publications on the Yorkshire area will be found in the body of the work, but I would here express the obligations which the Geological Survey owes especially to the classic work of Phillips and to the writings of Messrs. Tate, Blake, and Hudleston.

The figures of characteristic fossils inserted in the text of the present volume are photo-zincographic reproductions of drawings, made by Mr. W. Redaway under the direction of Messrs. Sharman and Newton, Palæontologists of the Geological Survey. Those marked "original" have been drawn from specimens in the collections of the Geological Survey in the Museum of Practical Geology, Jermyn Street. These illustrations are intended to familiarise the eye of the reader with some of the organic forms which are of special value as guides to the successive stratigraphical horizons.

Among the contents of the volume a special interest attaches to the hitherto unpublished Memoir on the Hackness Hills, by William Smith, the Father of English Geology, which will be found in the Appendix.

I trust that this present work may be deemed worthy to take its place as a standard book of reference for the subject of which it treats.

ARCH. GEIKIE.

Geological Survey Office,
28, Jermyn Street, London,
28th April 1892.

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THE

JURASSIC ROCKS

OF

YORKSHIRE.

CHAPTER I.

INTRODUCTION.

Physical Features: Classification of the Rocks, and their Relation to the Form of the Ground.

THE North-Eastern portion of Yorkshire forms an extensive and elevated tract rising abruptly from the low ground in the centre of the county through which the Ouse and its tributaries flowing to the south, and the Tees flowing to the north-east take their course towards the sea. This valley, which is known in different parts of its course as the Vale of York, the Vale of Mowbray, and the Vale of Tees or Cleveland, is really one great plain separating these eastern ranges of hills from the older palæozoic rocks of the western part of the county.

When viewed from this low ground the elevated region on the east is seen to rise at first gradually in a series of low undulating hills, never more than a mile or two in breadth, behind which the more massive beds of the series run up abruptly in a series of escarpments and precipices to an altitude in many cases of over 1,000 feet above the plain. Although there is no evidence that this inland escarpment has ever been a sea-cliff, the resemblance of these bold promontories and outlying hills, with their deep bay-like recesses, to an old line of coast is very striking. The lower slopes of these hills being enclosed and cultivated, and dotted with many parks and villages, gives an idea of prosperity and population, which is in remarkable contrast to the bleak and desolate moorlands that rise beyond; and which, with the exception of the interior valleys, cover so large a portion of the district to the eastward.

The Jurassic Rocks, composing these ranges of hills, and which are described in the following pages, are separable into four

main divisions, giving rise to different types of country, each of which affords a distinct class of scenery. These are the Lias, the Lower Oolite, the Middle Oolite and the Upper Oolite. The first of these, which consists mostly of shales, crops out beneath the great outer escarpment and in many of the interior dales, where it forms a narrow band of cultivated ground that is usually somewhat steep, but occasionally spreads into low undulating country that covers a broader area.

The Lower Oolite, composed principally of alternations of sandstones and shales, occupies the greater part of the central and northern region, where it has produced, over the greater part of the area, a tract of elevated moorlands having in general a rounded outline, except in those places where the thick beds of sandstone have formed more prominent escarpments.

The Middle Oolite, which is mainly formed of massive beds of sandstone and limestone, constitutes the Tabular range of hills, encirling the Vale of Pickering. These rise abruptly above the Lower Oolite in a bold escarpment, and spread out into extensive elevated plateaus intersected by sharply cut valleys, whose angular contour is in striking contrast to the rounded and more flowing outline of the beds beneath. The Upper Oolite, which is represented here only by shales, occupies the great depression in the south part of the area known as the Vale of Pickering; and forms a broad, nearly level valley, except towards the western end, where it rises into a few isolated hills. To the south of Malton this formation forms the steep clayey banks beneath the Chalk escarpment, which is the boundary of the south-eastern part of the district.

Although this is the general character of the four regions enumerated above, it is often modified by various local circumstances. The chief of these is the presence of Boulder Clay and other Drift deposits over a portion of the country. It is, however, chiefly around the outer portion of the district that these deposits are now found; the central hill ranges are entirely free from all such material. Thus the only areas covered by Drift are a narrow strip along the coast, the outer flank of the great western escarpments, and the larger depressions of the Esk and the Vale of Pickering. It would seem as if these central hill-ranges were held by local ice during the Glacial Period, which effectually withstood the vast streams that overflowed the country on either side. One peculiar circumstance connected with the Glacial Deposits is the fact that they rise to a considerably greater altitude along the northern face of these hills than elsewhere, and gradually decline to the southward, as if the force by which they were propelled was greater in that direction. In consequence of the ground being covered with these deposits there is greater fertility in this outer region, and over a great portion of the two larger valleys, where the soil is richer and better cultivated, than is possible over the stiff Lias clays or cold Oolite shales of other parts.

The following are the subdivisions of these four main groups of strata adopted in the present Memoir:—

Jurassic.	Upper Oolite		Portlandian Beds.
			Kimeridge Clay.
	Middle Oolite	Corallian Series.	Upper Calcareous Grit, and North Grimstone Cement-stone.
			Upper Limestone and Coral Rag.
			Middle Calcareous Grit.
			Lower Limestone.
			Greystone or Passage Beds.
			Lower Calcareous Grit.
			Oxford Clay.
			Kellaways Rock.
	Lower Oolite		Cornbrash.
		Inferior Oolite Series.	Upper Estuarine Series.
			Scarborough or Grey Limestone Series.
			Middle Estuarine Series.
			Millepore Series, and Whitwell or Cave Oolite.
			Lower Estuarine Series, including the Eller Beck Bed and Hydraulic Limestone.
			The Dogger, and Blea Wyke Beds.
	Lias	Lias.	Upper Lias.
			Middle Lias.
			Lower Lias.

These rocks terminate on the north, west, and a great part of the south in a line of bold escarpments, which is the natural outcrop of the strata; while on the east they are cut off by the sea, and give rise to a series of grand cliff sections. Thus they form a compact district bounded by marked physical features that entirely separate it from the surrounding country. Not only are the Jurassic rocks of this region now separated from the contemporaneous strata of other parts of England, but their character also indicates that during the greater part of the Jurassic period it was a distinct area which was unconnected with that to the south. For this reason the north-eastern part of Yorkshire forms a unique district. It is more convenient to take this separately, in describing the Jurassic rocks of England, than to include a portion of the midland counties; although the latter plan would more equably divide the whole.

The general figure of the district is, roughly, circular, having a diameter of about 40 miles, and an area of over 1,000 square miles. It includes several ranges of hills, which in one or two cases rise to over 1,400 feet in altitude, and are mostly in the state of wild moorlands, but are intersected by numerous deeply cut valleys that are generally cultivated, and considerably add to the beauty of the scenery.

The physical structure of the greater part of the district is on the whole very simple. The larger rock masses form marked lines of feature, separated from one another by the thicker beds of clay or shale, and give rise to regular ranges of hills that traverse the country in certain definite directions. The general strike of the strata being in the form of a semicircle, the dip is on the whole towards the centre. In consequence of this the principal ranges of hills are along the outer margin, and decline

towards the interior, with a few exceptions due to other causes.

Commencing along the northern border a range of elevated ground starts from the sea-coast in the lofty cliffs of Huntcliff and Boulby, and striking westwards divides into two lines, the northern forming the outlying hills of Upleatham and Eston, the southern passing to the south of the great inlet in which the town of Guisbrough is situated, where it forms that part of the Cleveland Hills known as Guisbrough Moor. Here, owing to a local uplifting of the strata in an east and west direction, the most elevated ground curves round to the east, and forms the range of hills on the northern side of the valley of the Esk stretching away to Danby Beacon and beyond.

Crossing the valley of the Esk the main range of hills skirts round the bay-like depression of Ingleby Greenhow, past Burton Head, the greatest elevation in the whole district, the remarkable hill of Hasty Bank at the head of Bilsdale, and the other outliers between here and Whorlton. At this point the escarpment turns south, and these lower strata, which have formed the northern hills, become capped by higher beds, the whole rising in the bold headland of Black Hambleton to an altitude of 1,309 feet. We here leave the Cleveland Hills, and the character of scenery undergoes a complete change. Instead of the rounded outline, which is the general appearance of the northern hills, these southern ranges have nearly level tabular summits with steeply scarped sides, and intersected by numerous narrow trench-like valleys. This elevated ground, which is known by the general name of the Tabular Hills, encircles the western end of the Vale of Pickering in the form of a horseshoe; and, dipping towards that valley in more or less gentle slopes, presents a bold escarpment along its outer edge.

The northern arm of these hills, to which the name of the Tabular range is more particularly applied, extends in a nearly east and west direction from the sea-coast near Scarborough to Black Hambleton. At this point the high ground curves round to the south and forms the lofty plateau of the Hambleton Hills,* which are sharply cut off on the south by the remarkable valley running from Gilling to Coxwold. This valley, which is one of the few instances of those that are mainly due to the faulting of the strata, separates the central mass of the Tabular range from the less elevated ground of the Howardian Hills, which forms the southern arm extending along the edge of the Vale of Pickering between Gilling and Malton. Along this tract of country the strata dip northwards; so that, while the higher beds on the northern side form a range of much regularity, towards the south lower strata crop out, producing a more undulating outline, and giving rise to a type of scenery of much beauty and variety.

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* The name Hamildon or Hambleton is said to be derived from "Hemel" and "don" or "dun," signifying the Heavenly mountain. Grainge, Vale of Mowbray, p. 349.

Besides the ranges of hills above described, a tract of high ground extends along the southern side of the Esk valley from Burton Head to the coast, where it terminates in the bold line of cliffs about Peak and Robin Hood's Bay. This range may be said to be the backbone of the country, as it separates the watersheds of the northern streams from those of the Derwent and its tributaries flowing south. This part of the district is mainly in the state of open moorland, but it is intersected by numerous deeply-cut valleys that are the site of many a sheltered homestead.

The drainage of the country, with the exception of quite the outer slopes, is effected by the two main streams of the Esk and the Derwent with their tributaries. The former of these drains the large district lying between the two parallel watersheds that extend eastwards from the main watershed on Guisbrough Moor and at Burton Head to the sea-coast on either side of Whitby.

Beyond this latter range all the streams flow south; those in the west, which cut deeply into the lower part of the Jurassic series, break through the escarpment of the Tabular range, and join the Rye in the Vale of Pickering; while those in the east, which do not possess such deeply-cut valleys, join the Derwent, which breaks through the Tabular range at Hackness, and flows westwards along the Vale of Pickering till it joins the Rye a little above the town of Malton, where the united streams again break through the whole series of Jurassic rocks, and flow southwards to the Humber. The courses taken by these streams are very remarkable, but to this subject we shall refer again later on.

Besides these two main river basins, there are only the narrow areas along the coast, and beneath the outer range of hills. The former of these is drained by rivulets flowing direct to the sea: the latter by small streams that are tributary to either the Tees or Ouse.

General Sketch of the Distribution of Population and Industries.

Although a large part of the area is too bleak and cold to be capable of cultivation, still there are many parts where the ground being less elevated is enclosed, and devoted to purposes of agriculture. This is especially the case along the Esk and many other streams; beneath the great outer escarpment; and along the sea-coast; but more particularly throughout the great Vale of Pickering which is watered by the united streams of the Rye and Derwent in the southern part of the district.

Consequently the most populated areas, and the sites of the chief towns and villages, are either around the outer margin of the district, or along its interior valleys. Thus along this outer flank, besides the numerous small hamlets and scattered houses which cover the slopes of these hills, the principal places are Kirkby Underdale, Acklam, Leavening, Sheriff Hutton, Farlington, Stillington, Easingwold, Thormanby, Husthwaite, Coxwold, Kilburn, Feliskirk, Cowesby, Kepwick, Silton, Osmotherley,

Stokesley, Ayton, Kildale, and Guisbrough*; while just beyond are the more important towns of Thirsk, Northallerton, Stockton, and Middlesborough. This latter, whose rise and progress is one of the most remarkable instances of commercial prosperity in this country, is the headquarters of the great iron industry, which owes its origin to the vast stores of that mineral contained in the lower strata, cropping out in the northern part of the district, and which on that account is considerably the most populous area. This region, which is generally known by the name of Cleveland, includes among its most important places, Redcar, Coatham, Marske, Saltburn, Skelton, Brotton, Skinningrove, Lofthouse, Liverton, Kilton, and Boosbeck.

Along the coast, besides the towns of Whitby, Scarborough, and Filey, there are the fishing villages of Staithes, Runswick, Sandsend, and Robin Hood's Bay; some of which since the completion of the railway are likely to become more or less popular seaside resorts; while a short distance inland are the agricultural villages of Easington, Rousby, Hinderwell, Lythe, Mickleby, Hawsker, Cloughton, Burniston, Scalby, and Hackness. This latter neighbourhood is interesting to geologists from its having been the home of W. Smith for a number of years; and also for the clearness and diversity of its geological structure, as well as for the great beauty of its deep ramifying valleys.

Over the remainder of the district the principal centres of population are scattered along the Esk, the Vale of Pickering, and the several minor dales that are tributary to these. In the valley of the Esk there are no towns with the exception of Whitby at its mouth, but many villages are dotted along its sides, the principal being Castleton, Danby, Lealholm Bridge, Glaisdale, Egton, Grosmont, Sleights, Sneaton, and Ruswarp.

Next to the Cleveland mining district the Vale of Pickering is the most populous and prosperous part of the whole district, including as it does the towns of Malton, Helmsley, Kirkby Moorside, and Pickering, with the string of villages which mostly lie on the flanks of its central plateau. These are Cayton, Seamer, Ayton, Hutton Bushel, Wykcham, Brompton, Snainton, Ebberston, Allerston, Wilton, Thonton Dale, Middleton, Aislaby, Wrelton, Sinnington, Welburn, Wombleton, Nawton, along the northern side; Sproxton, Nunnington, Salton, Normanby, Marton, Edston, Kirkby Misperton, and Yedingham, at the western end or along the centre of the valley; Hovingham, Slingsby, Appleton, Rillington, Scampston, Wintringham, Heslerton, Sherburn, Ganton, Staxton, Flixton, Folkton, and Muston, along the southern edge. In the smaller dales, besides the detached houses and farmsteads which are frequently very numerous, there are the more important villages of Hawnby, Chop Gate, Rosedale Abbey, Hutton-le-Hole, and Lastingham.

* Often spelt Gisborough (Domesday, Ghigesburgh).

The higher ground in the northern part of the district is, as we have noticed, entirely moorland; but the hill-ranges surrounding the Vale of Pickering, not being so bleak and wild, are frequently brought into cultivation; the consequence is that many villages are scattered over their surface, some in the less exposed situations being even on the hill tops. These are Sawdon, Lockton, Levisham, Newton, Cropton, Appleton, Spaunton, Gillamoor, Fadmoor, Pockley, Carlton, Old Byland, Cold Kirkby, Scawton, Ampleforth, Oswaldkirk, and Stonegrave on the north and west of the Vale of Pickering; while on the Howardian Hills, to the south of that valley, there are Oulston, Yearsley, Brandsby, Gilling, Colton, Dalby, Terrington, Ganthorpe, Coneysthorpe, Stittenham, Bulmer, Welburn, Hutton, Whitwell, Crambe, Weston, Langton, Burythorpe, North Grimston, and Birdsall.

The resources of the country are mainly agricultural, with the exception of the northern area, where the discovery of the Cleveland ironstone has effected a complete revolution, and converted the quiet pastoral dales into busy populous districts. Along the coast the chief industry is fishing, which in the principal towns is largely supplemented by their being important residential places and popular summer resorts. Many of the rocks form good building stones, and abundance of lime is afforded by the purer limestones; the Oolite shales and Drift clays are also much used for brickmaking and other purposes. Peat is the chief source of fuel in the more remote districts away from railways; but further details on these subjects are given in the chapter on economic products.

History of the Progress of Geological Knowledge concerning the Jurassic Rocks of Yorkshire, with a brief account of the more important Publications.

In this sketch of the progress of geology among the Oolites and Lias of Yorkshire, we need not consider all the notices that have been written on matters connected with these rocks. Several of them refer only to particular subjects,—for instance, to its agriculture, to palæontology, or other special researches; most of these will be dealt with in the subsequent chapters. A full list of all the publications with which we are acquainted will be given in a separate volume.

The earliest notice we have of geological observations in Yorkshire are those of Dr. Martin Lister, who resided in the county, and about the year 1671 made extensive collections of fossils from different localities.* Although Lister considered these *Cockle-like stones* to be *Lapides sui Generis,* and that they never were any part of an *Animal,* he nevertheless recognised that they

* There are several papers by Dr. Wittie and others on the Scarborough Spaw in 1660 and following years, but they appear to have treated the subject chiefly from a medicinal point of view, although Dr. Wittie correctly attributes its origin to the action of rain water percolating the earth and dissolving the various minerals with which it comes in contact.

differed from recent species and also were peculiar to certain rocks or quarries.* He also noticed the continuity of the main groups of strata over large areas, and the intimate connection between different soils and the rocks below. This led him in 1683 to propose to the Royal Society a Soil or Mineral Map, in which he takes Yorkshire, where the limits of each group are very well defined, by way of example, and gives the following divisions† :—

1. *The Wolds;* Chalk, Flint, and Pyrites, &c.
2. *Blackmoor;* Moors, Sandstone, &c.
3. *Holderness;* Boggy, Turf, Clay, Sand, &c.
4. *Western Mountains;* Moors, Sandstone, Coal, Ironstone, Lead-ore, Sand, Clay, &c.

Dr. John Woodward‡ and several other authors during the seventeenth century allude to fossils that had been obtained from Yorkshire ;§ but their ideas at this early period were very crude, and do not throw much light on the geology of the county.

During the latter part of the eighteenth century we have the careful observations of the Rev. John Michell, Woodwardian Professor at Cambridge, who in 1760 published a paper "On the Cause and Phenomena of Earthquakes."‖ In this paper, which is accompanied with a section that shows he fully recognised the general laws of stratification, he noticed the regular superposition of beds above one another, and the frequent parallelism of their outcrop to ranges of mountains. About 1770 Michell came to reside at Wakefield in Yorkshire, and during several journeys between that place and Cambridge compiled a table of strata from the Chalk to the Coal Measures. Michell also appears to have been acquainted with the Liassic strata about Whitby, as in the paper above quoted he says, "Numberless instances of this [the conversion of vegetable bodies into pyrites or coal] are to be met with in the aluminous shale of Whitby and other places. . . . . . . The aluminous earths, moreover, not only have several strata of iron-ore lying in them, but they also contain a considerable proportion of iron in their composition."¶

In 1816 N. J. Winch read a paper before the Geological Society,** in which he divides the eastern part of Yorkshire into three ranges of hills after the manner of Lister:—

1. The eastern moorlands, or alum-shale district.
2. The oolite limestone hills, rising to the south-west of Robin Hood's Bay.
3. The Wolds, composed chiefly of hard chalk.

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* Phil. Trans., vol. v. no. 76, p. 2282. Lowthorp's Abridgment, vol. ii. p. 425.

† *Ibid.*, vol. xiv. no. 164, p 739.

‡ Essay towards a Natural History of the Earth, 1695. Preface.

§ An attempt towards a Natural History of the Fossils of England, &c., or a Catalogue of English Fossils, in the collection of J. Woodward, M.D. 2 vols. Lond., 1728, 1729.

‖ Phil. Trans., vol. li. Part II., p. 566, &c. Abridgment, p. 448.

¶ *Loc. cit.*, p. 591.

** Trans. Geol. Soc., vol. v. p. 545. This paper, although read in 1816, was not published till 1821.

He accurately points out the regular succession of the strata along the coast: showing that, the dip being to the south-east, group 2 passes beneath 3, while 1 passes beneath 2. This paper, although it does not enter into much detail, contains several accounts of borings for coal, and other valuable observations which show that the geology of the county was now beginning to be studied in a scientific manner. During this year also appeared the Scarborough Catalogue,* which is interesting as being the earliest publication specially devoted to the fossils of the districts, and consequently has been occasionally referred to by Sowerby and others. This curious work is, however, more interesting from a historical than a geological point of view.

The great observer, however, who was destined to place English geology on a surer foundation than it had previously obtained, was William Smith, who, noticing in the country round Bath that different groups of strata might be identified by their peculiar organised fossils, drew up in 1799† a "Table of the Order of the Strata near Bath," wherein he proposed a classification of the stratified rocks in the order of their relative antiquity with a list of their organic remains.‡ From the time of the appearance of this Table he continued to collect memoranda for his large map of England, which, however, owing to numerous vexatious delays, was not completed till 1815. This map, which is a marvel of perseverance and natural ability, is in many respects more accurate than the county map published subsequently; and, although the scale is much smaller, greater detail is shown in some parts. But it was prior to this, in 1794, that Smith, in connection with his duties as a surveyor, made his first tour north; and, in passing the Hambleton Hills, recognised in them the features of the Cotteswolds, although it was not till the year 1803 that he made any permanent stay in Yorkshire. Subsequently he made several journeys in different parts of the county, the geological results of which were published in 1821 in the large four-sheet map of Yorkshire. This map, which was the first attempt to show the areas covered by different geological formations on so large a scale,§ is, considering the disadvantages under which it was done, very accurate, except that Smith does not appear to have recognised the Oxford Clay, but to have confounded that formation, under the name Clunch Clay, with the Lias or Alum Shale.

* A Descriptive Catalogue of the Minerals and Fossil Organic Remains of Scarborough and the Vicinity. Anon. [Rev. F. Kendall]. 8vo. Scarborough, 1816.

† In Conybeare and Phillips' Geology, and in Lyell's Principles, the date is given as 1790, but this seems to be an error.

‡ See Notes on English Geology, by Dr. Fitton. Phil. Mag., ser. 3, vol. ii. p. 37, and Memoirs of W. Smith, by Prof. J. Phillips. 8vo. London, 1844.

§ There is a general map of the north of England published by the Board of Agriculture in 1794, which shows the outcrop of the main divisions of the strata that have a marked effect on the soil. See Marshall, Review of the Reports of the Boards of Agriculture, vol. i., 1818. There is also a small map published by Tuke in 1800.

Smith, in his maps and other publications, frequently adopted English provincial names for the different members of the strata; and hence we get such odd words as, clunch clay, cornbrash, &c.

From 1828 to 1834 Smith resided at Hackness, and it is probable that while here he made the large scale map of that estate, which shows in a remarkable manner his accurate and detailed knowledge of the strata.* This map, the scale of which is about equal to the six-inch map of the Ordnance Survey, is a good example of what a plan of an estate should be. On it the greatest detail is shown, even to minute lithological divisions; thus, on account of the marked effect they have upon the agriculture of the district, the outcrop of such thin bands as the Coral bed at the base of the Limestone, and the sands in the upper part of the Lower Calcarous Grit are shown as distinct beds.

During the early part of the century the study of British organic remains began to be taken up, partly through the memoirs of Smith himself, but chiefly owing to the appearance of the well-known work, Sowerby's Mineral Conchology. This work, which, with the exception of Parkinson's Organic Remains, was the first systematic attempt to describe British fossils, was commenced in 1812 by James Sowerby, and continued from 1825 to 1829 by his son, J. De Carle Sowerby. In it are figured and described a number of Yorkshire specimens which were sent to Sowerby, his attention to this county having been apparently drawn by the publication in 1816 of the Scarborough Catalogue. This latter, however, is little more than a list of the minerals and fossil organic remains found along the Yorkshire coast, nevertheless it contains a few very fair plates, some of which are quite equal to, if not better than, those of the Mineral Conchology.

In 1819 G. B. Greenough published the first edition of his map, which is nearly on the same scale as Smith's large map of England, and is in fact to a great extent based upon that work. From the progress of geological knowledge during these four years many imperfections of Smith's map were removed; and, from the general topography of the country being more accurately delineated, the geological details were able to be put in more exactly. In the Yorkshire portion, however, this map is far less accurate than that of Smith; and although the error with regard to the Lias is corrected, the clay of the Vale of Pickering is represented so incorrectly as to show that its stratigraphical position was not fully recognised. Greenough, in his Geology, notices the marked false-bedding in the Millepore Bed near Westow, where he says horizontal beds of oolite may be seen resting on highly inclined ones.† He also alludes to the fissure which "disturbs indiscrimately in its progress all the beds

* MS. map in the possession of the late Mr. R. Turnbull, Hackness; of which a few lithographed copies are in existence. See description of this map given in the Appendix.

† A Critical Examination of the First Principles of Geology. G. B. Greenough. 1819. p. 14.

which are interposed between the oolitic series and that of the mountain limestone."*

The names of Prof. Buckland and William Conybeare must also at this period be associated with the geology of north-east Yorkshire; for although they did not write anything specially on the Jurassic rocks of the northern part of England, yet their papers contain frequent allusions to these strata, showing that they were well acquainted with them, and were able to correct many errors which existed at that time.

The great work of Prof. Buckland is, however, the Reliquiæ Diluvianæ, which, although it refers to a later geological epoch, cannot be omitted from a list of publications bearing on the district. This work, which appeared in 1823, was preceded by an account of Kirkdale Cave in 1822.† It gives a small geological map showing the situation of the cave, and a short account of the strata in the neighbourhood.

Among W. D. Conybeare's geological works we may more particularly notice, as referring to the geology of the district, the "Outlines of the Geology of England and Wales"‡; which remarkable work, undertaken in conjunction with W. Phillips, may be considered the first general systematic account of the subject; and a paper on M. de Beaumont's Theory of the Parallelism of Contemporaneous Lines of Elevation.§ In the first of these works the authors appear to have had considerable doubts as to the correlation of the several Yorkshire deposits with those of the rest of England.

About this time appeared Young and Bird's "Geological Survey of the Yorkshire Coast." This work, which was published in 1822, was the first attempt to systematically describe the geological structure of north-east Yorkshire, and to point out some of the principal faults and dislocations. The Rev. G. Young had in 1818, in his "History of Whitby and the Vicinity," previously described the geology near that town, and this information was included in the larger work of the joint authors.

The Jurassic Rocks were divided by them into the following eight groups:—

The Upper Shale, which included the Neocomian and Kimeridge Clays.
The Oolite, which included the Coral Rag and Oolite Limestone around the Vale of Pickering; and also (erroneously) the Oolite of Whitwell.
Limestone and Calcareous Sandstone, which included the remainder of the Middle Oolite Limestones and the Lower Calcareous Grit.
The Second Shale, which included the Oxford Clay of the coast and the north and west escarpment. The Kimeridge Clay on the northern side of the Vale of Pickering and about Malton; the Estuarine shales about

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* A Critical Examination of the First Principles of Geology. G. B. Greenough, 1819. p. 308.

† Phil. Trans., vol. cxii. p. 171, and Ann. of Phil., ser. 2, vol. iv. pp. 133, 173. There are also several publications by other authors referring to the remains found at Kirkdale during the years 1823 and 1824.

‡ Outlines of the Geology of England and Wales. 1822. Pages 270–272 more particularly refer to Yorkshire.

§ Phil. Mag. ser. 3, vol. i. p. 118. Pages 124 and 125 allude to Yorkshire.

Scarborough; and the Lias of Kirkham were also referred to this division.

Ironstone and Sandstone, which included the Kellaways Rock and Lower Oolite Sandstones south of Cloughton; but were not recognised north of this, nor in the interior except in Newton Dale.

Blue Limestone. Under this head was described the Grey Limestone of Cloughton and the coast to the north, as well as across the moors to the Hambleton escarpment.

Sandstone, Shale and Coal, included the remainder of the Lower Oolite not described under the above heads.

The Great Beds of Alum Shale, included the whole of the Lias although the difference between the upper, middle and lower beds is pointed out. The Upper Lias is called the main bed of alum shale; the Ironstone Series and Sandy Series of the Middle Lias are described as they appear on the shore under the names of Kettleness Beds and Staithes Beds respectively; while the Lower Lias receives the name of the lowest bed of alum shale.

This is the first time the Oxford Clay and Grey Limestone were traced out as distinct beds, and separated from the other strata.

A map accompanies this work, but the outcrop shown for the Oolites, and Lias is so incorrect as to be absolutely valueless.

This work was the second attempt to figure and describe the fossils of the district, but on a much more extended scale than in the Scarborough Catalogue. The figures are, however, rather rough; and the descriptions of them not being very clear, it is only in a few cases that the species of these authors have been retained. The publication of this work led to some unseemly wrangles between its authors and Sowerby; these arose from a misunderstanding with regard to the specific determination of *Ammonites armatus*, which Young seems to have confounded with *Am. fibulatus*.*

There is no doubt, however, that the appearance of Young and Bird's work did much to arouse the desire for geological pursuits, which eventually led to the establishment of the museums at Whitby and Scarborough, and to the formation of such collections of fossils as were made by Bean, Williamson, and others. Martin Simpson, in describing the state of scientific knowledge at this time says, " The publication of this work [Young's History of Whitby] immediately produced a general revolution in public opinion respecting the fossil remains of the district, and excited great zeal for further discovery. There was indeed at this time, in Whitby, a strong desire after intellectual pursuits, not only amongst the learned, but among many whose circumstances in life were unfavourable to such pursuits. The cessation of a long and exhausting war, the energies aroused by that war, and the want of employment before the return of commercial prosperity, all had a tendency to intellectual pursuits, and, no doubt, constituted greatly to the establishment of Philosophical Institutions and Museums, which the great wealth and the national prosperity of the present era scarcely sustain."†

* See Wright, Lias Ammonites, p. 341.
† Simpson, Fossils of the Yorkshire Lias, p. iv. 1884.

In 1826 Prof. Sedgwick published a paper, "On the Classification of the Strata which appear on the Yorkshire Coast,"* from memoranda collected in 1821; but, as the work of Young and Bird had appeared in the meantime, he restricted his description to the Coast section, which he correlates with the several formations seen in other parts of England, pointing out that at this time the best geological authorities were at variance amongst themselves with regard to these beds. In this paper the Speeton Clay is referred to the Kimeridge formation, but the peculiarity of the fauna of the upper portion is noticed. The rocks occupying the high broken tract of country between the Vale of Pickering and Huntcliff are divided into three groups:—

1. Oolite limestone and Calcareous grit.
2. Coal formation.
3. A great argillaceous deposit (alum shale or lias).

The first of these had already been identified by Greenough, Buckland, and Smith with the Coral Rag; but Sedgwick seems to have been rather doubtful about the shale beneath, which he originally considered to be Oxford Clay; although he afterwards thought it to be subdivided by beds of sandstone, and therefore "not a distinct deposit, but a subordinate member of a complex formation."† In group 2 he noticed the position of the Moor Coals and Dogger very accurately: he also refers to the Grey Limestone at Cloughton, and the Millepore Bed south of Scarborough. Group 3 he divides into three sub-groups, as was done by Young and Bird, and points out that these beds are certainly the equivalent of the Lias of the south of England and not of the Clunch clay.

During the same year (1826) "An Account of the Strata North of the Humber, near Cave," ‡ was published by the Rev. W. Vernon, which accomplished for South Yorkshire what had been done for the north, and filled up the blanks left by Young and Bird, and Sedgwick. In the excursion, of which this paper is a description, Vernon was assisted by John Phillips, who had previously with Smith detected in North Yorkshire three members of the southern series not before observed, and had established the following order:—

Calcareous Grit.
Oxford Clay.
Kellaways Rock.
Cornbrash.
Calcareous and sandy beds = inferior oolite.

Prof. Phillips recognised the "Kelloway Stone" at Newbald to be the same as that at Scarborough, and the connecting link of the Lias to Brough was now made out for the first time; the existence of the ironstone at Everthorpe being also noticed. A small map of the district is made, in which the outcrop of the Kimeridge Clay, the Kellaways Rock, the Oolite, and the Lias is shown with considerable accuracy.

* Ann. of Phil., ser. 2, vol. xi. p. 339.
† *Ibid.*, p. 353.
‡ *Ibid.*, p. 435.

During this period other observers also were at work in this part of the country, and assisted either by their publications or collections in advancing its geology. Of these we may mention Dr. Murray, J. Dunn, W. Bean, J. Williamson, and Sir R. I. Murchison*—the first four of whom resided at Scarborough, and, together with W. Smith, formed a scientific circle to whose exertions the origin of the Philosophical Society of that town is due.† The collections of recent and fossil shells made by Bean and Williamson formed the nucleus around which the labours of more recent observers have gathered, and laid the foundation for the accurate determination of the Yorkshire Jurassic rocks.‡ Prof. Phillips in his Memoirs of William Smith alluding to this period, says, "At this time the well-known naturalist Mr. Wm. Bean, who had long possessed a magnificent collection of the Testacea and other recent productions of the Scarborough coast, had begun to gather that large and exquisite series of organic remains which enriches this beautiful museum. Mr. John Williamson was in full activity, and had already laid the foundation of the collection afterwards transferred to the Museum of the Scarborough Philosophical Society. The rich hoard of Speeton fossils was almost untouched—almost unexamined since the days of Lister,—the plants of Gristhorpe were unknown, but a spirit of geological research began to spread among the residents and visitors of Scarborough that promised the happiest fruits.

"In this pleasant excitement no man had a truer delight than Mr. Smith. He loved to wander beneath the cliffs, noting the minutest variations in the stratification, detecting the slightest marks of dislocation, watching the peculiarities of the sea's action on materials of unlike qualities, and inferring the causes which had anciently modified the outline of the land, and covered the low cliffs of the oolitic series with fragments of the lias from Whitby, of the coal and limestone from Teesdale or Swaledale, and of the granite and sienite from Shap Fells and Carrock Pike. In numerous papers dedicated to the local geology of Scarborough his reflections on these subjects are recorded."§

We next come to the important and well-known work of Prof. Phillips, "Illustrations of the Geology of Yorkshire," the first part of which "The Yorkshire Coast" was published in 1829.‖ This work treats of the subject in a more philosophical manner

* Sir Rod. Murchison visited Yorkshire on his way to Scotland in 1826, and studied the coast section under the guidance of Smith and Phillips, but he did not publish anything specially on the district except the short paper in the Proc. Geol. Soc., vol. i. p. 391.

† The Museum was built in 1828. The Whitby Museum having been previously established in 1823, and become the receptacle of the gigantic *Teleosaurus Chapmanni*.

‡ There is an admirable account of the life of John Williamson, and of the state of scientific knowledge in the district at this period, by his son Prof. W. C. Williamson, in the Proc. of the York. Geol. and Polytech. Soc. New ser., vol. viii. p. 295.

§ Phillips's Memoirs of William Smith, p. 110.

‖ A second edition of this work was published in 1835, but as little new is added it is almost a reprint of the first edition. The third edition, published in 1875, we shall allude to further on.

than any prior publication; it traces the principal divisions of the strata with so much accuracy that its main features have been retained to the present day, and form the basis of all subsequent work on the district. The thickness of each formation is given, and also very copious lists of fossils, with authorities and localities for each species. With regard to new species, unfortunately he gives no description of those figured, consequently it is not always easy to identify his species. There is also a small map, which, although the scale is only about 8 miles to the inch, is more accurate than anything previously attempted. Phillips separated the clay of the Vale of Pickering into two divisions, Gault? and Kimeridge Clay, pointing out the striking difference in the fossils from the upper portion, and noticing their resemblance to those of the "Gault." The Middle Oolite, under the name Coralline Oolite formation, was described under five heads, most of which are the same as those now accepted; although the tracing out of the separate beds of sandstone and limestone in the upper part has led to more accurate information of these strata, and corrected some slight errors. The Lower Oolite, which Phillips considered to be the equivalent of the Bath Oolite, was separated into three calcareous and two arenaceous series, and consisted of five divisions:—

Cornbrash limestone.
Upper sandstone, shale, and coal.
Impure limestone. (Oolite of Lincolnshire.)
Lower sandstone, shale, and coal.
Ferruginous beds. (Inferior oolite and sand of Somersetshire.)

The upper coal series and the lower coal series do not, however, always include exactly equivalent horizons, from the fact of it not being recognised that the Grey Limestone and the Millepore Bed were separate rocks. This error arose probably from the great thinning out which takes place in these limestones in opposite directions; so that the Grey Limestone of the north was supposed to be the same bed as the Millepore Oolite of Gristhorpe and the Howardian Hills.* The Lias was divided for the first time into Upper, Middle, and Lower, as had been indicated by Young and Bird, and Sedgwick; the Middle Lias being correlated with the Marlstone of the Midland counties, the fossils from which are shown to be identical. When we consider the period at which this work was produced, and the very rudimentary state of Palæontology at that time, we must allow that it was a great advance upon anything at the time; it is not surprising, therefore, that there should have been some confusion among the thin marine beds of the Lower Oolites, and in their correlation with those of other districts.

After the appearance of this important work little appears to have been published on the geology of the district for nearly a decade; although no doubt the scientific circle at Scarborough

* This error was, however, corrected in the third edition, 1875, having been previously noticed by Prof. Phillips in a paper, read in 1857, on the Yorkshire Oolites. Quart. Journ. Geol. Soc., vol. xiv. p. 84.

and others were making observations which bore fruit in the several short papers catalogued in our bibliographical list. Most of these referred to special subjects, the only ones of any note or of more general application being that of Louis Hunton on a "Section of the Upper Lias and Marlstone of Yorkshire;" and that of Prof. Williamson on the "Distribution of Fossil Remains on the Yorkshire Coast;" the first part of which appeared in 1837, and was followed in 1841 by a second part, continuing the description to the Oxford Clay.* The former of these, although referring only to a particular section and only to a portion of the Lias, was the first attempt to separate the strata into zones, and to demonstrate that certain fossils were restricted to definite horizons. This was further carried out by Prof. Williamson, who, adopting the main divisions of the Lias and Oolites already set forth by Phillips, pointed out in a more marked manner the characteristic organic remains of each.

During the next ten years considerable progress was made in the science of palæontology; several important works were published on the Continent, including those of Quenstedt, Römer, Dunker, Agassiz, D'Orbigny, Bronn, and others, while in England the monographs of the Palæontographical Society were commenced. Of these latter the work which had the chief connection with the Yorkshire Jurassic Rocks was the well-known monograph of Morris and Lycett, which was commenced in 1850 with the description of the univalves, and continued in 1853 and 1855 with the bivalves, being completed in 1863 with a supplement by Dr. Lycett, in which a large number of Yorkshire shells are figured and described. This work, although intended to refer only to the mollusca of the Great Oolite, nevertheless, from the error as to the age of the Yorkshire Inferior Oolite, included a large number of species from that formation. Other monographs of the Palæontographical Society, as well as the numerous communications to other publications, which were issued during this period, also referred to Yorkshire; all tending to show that the spirit of scientific inquiry was now thoroughly awakened, and that numerous workers were actively engaged in natural research.

In 1853 Prof. Phillips published his geological map of Yorkshire, on the scale of 5 miles to an inch. This, although only about half the scale of Smith's map, was considerably in advance of anything that had been prieviously attempted, and until quite recent years was the only authority on the topographical geology of the county. This map gives a good idea of the general run of the formations; but no dislocations are shown, and consequently the outcrop of some of the beds, especially where the ground is much faulted, is not very exact. A second edition of this map was issued in 1862.

About this time Dr. A. Oppel, who in his short life of 34 years did so much to make himself a name, visited England, and compared the Jurassic rocks of this country with those of the Con-

* Trans. Geol. Soc., ser. 2, vol. v. p. 215; vol. v. p. 223; vol. vi. p. 143.

tinent. The result of those observations were published in his "Juraformation Englands, Frankreichs und des südwestlichen Deutschlands," (1856–58) in which he gives a general view of the several zones into which the whole of the Jurassic rocks may be divided, and correlates the subdivisions of foreign authors with those adopted in England.

After the publication of this work the Yorkshire Oolites appear to have excited considerable attention, and several papers were written descriptive of these beds, correlating them with those in other parts of the country. The first of these was that by Dr. Lycett, in 1857, "On the Sands intermediate to the Inferior Oolite and Lias of the Cotteswold Hills," which, although referring principally to a different district, compared these beds with the similar deposits of the Yorkshire Coast.* The next year Prof. Phillips gave a detailed account of part of the Oolite and Lias of Yorkshire, in which he re-describes some of the sections given in his Geology of the Yorkshire Coast, but supplements that work by giving additional details of many inland exposures, especially along the western escarpment.† Phillips also shows the local variation in the beds, and indicates the leading points in the physical history of the period; although the further exposition of the subject is left for a future communication, which unfortunately never appeared.

This was followed by two papers by John Leckenby, one on the Kellaways Rock,‡ and the other on the Plant Remains of the Lower Oolite;§ in which the author gives copious lists, and many illustrations of the fauna and flora of those periods, for the preparation of which he had many facilities, both by his long residence in the district, and by his large collection of fossils.

The most important essay, however, which appeared about this time was that of Dr. Wright, "On the Subdivisions of the Inferior Oolite in the South of England, compared with the Equivalent Beds of that Formation on the Yorkshire Coast"‖; in which he gives a detailed account of the coast section. In this memoir it is argued that the Blea Wyke Beds are the equivalent of the Upper Lias Sands and the Cephalopoda Bed of Gloucestershire; it is also shown that the rest of the Inferior Oolite is capable of subdivision into three zones containing well-marked assemblages of fossils; and the whole are correlated, as had been done by Oppel, with equivalent beds on the Continent. In describing the Yorkshire beds, Dr. Wright points out that the fauna of the Grey Limestone is not that of the Great or Bath Oolite, as maintained by Prof. Phillips; but rather that it represents the Middle and Upper division of the Inferior Oolite. Only an experienced

* Ann. and Mag. Nat. Hist., ser. 2, vol. xx. p. 170; and Proc. Cotteswold Nat. Club, vol. ii. p. 142.

† Quart. Journ. Geol. Soc., vol. xiv. p. 84.

‡ *Ibid.*, vol. xv. p. 4.

§ *Ibid.*, vol. xx. p. 74.

‖ *Ibid.*, vol. xvi. p. 1. This subject was further considered in a communication to the Cotteswold Nat. Club in 1869.

palæontologist could have undertaken a work of this character, the physical difference being so great between the Jurassic rocks of the Yorkshire basin and those of the rest of England. This memoir has been ably supplemented by Dr. Wright's subsequent monographs for the Palæontographical Society on the Echinodermata and the Lias Ammonites, both of which have not only advanced our knowledge of those classes, but also have done much to elucidate many obscurities in Jurassic geology.

In 1861 Bewick published his "Geological Treatise on the District of Cleveland." Notwithstanding its rather pretentious title, this is a work of a very different order of merit from those we have previously mentioned; it, however, contains much local information as to the minerals of the district, and is accompanied by a map on the large scale of ¾ of an inch to a mile, about the accuracy of which perhaps the less said the better.

It is, however, during the last 20 years that the greatest additions have been made to our knowledge of the geology of the Jurassic rocks. During this period several memoirs have appeared both on the general subject of Jurassic geology and also devoted to this especial district, besides the numerous monographs which have been published on various branches of palæontology. In these, from the great advance which had been made in our knowledge of the rocks both in England and on the Continent, the authors were able to treat the subject in a more philosophical manner than had before been possible. The first of these was the short but careful description of Prof. Judd on the Speeton Clay (1868, 1870); which gave a detailed account of the Kimeridge and Neocomian Clays, and pointed out their relation to beds of the same age throughout Northern Europe.* This was followed in 1875 by the important memoir on the geology of Rutland, which, although mainly descriptive of another district, had a direct bearing on Yorkshire.† The former district, from its occupying a position midway between the northern and southern areas in which the Jurassic rocks are exposed, formed the key by which the apparent discrepancies in the classification between the two might be reconciled, and the strata of the one correlated with that of the other. In this memoir the question of the doubtful relations existing between the different members of the Lower Oolite is cleared up, and the Lincolnshire Limestone, which was previously considered to be of Great Oolite age, assigned to its true position in the Inferior Oolite.‡

Before proceeding further, it may be as well to give a short account of what had been the previous state of opinion on this subject, and to sketch the progress of events which enabled Palæontologists to arrive at a correct solution of this problem. In

* Quart. Journ. Geol. Soc., vol. xxiv. p. 218, and vol. xxvi. p. 326.

† Memoirs of the Geol. Survey. The Geology of Rutland.

‡ Prof. Judd was greatly aided in this work by the large local collection and extensive knowledge of Mr. Sharp, who published two papers on the Oolites of Northamptonshire. Quart. Journ. Geol. Soc., vol. xxvi. p. 354, and vol. xxix. p. 225.

the maps of Smith and Greenough these beds had been represented as contemporaneous with the Great Oolite, and had been considered as such by Phillips, Morris, and others, although it had been shown by Rev. W. Vernon, in a paper on South Yorkshire, that the fossils of the Cave Limestone were characteristic of the Inferior Oolite.* The correlation of these beds was, however, to a certain extent tentative, Prof. Phillips stating that he assigned the intercalated marine beds of Yorkshire to the Great Oolite, from the fact of their being newer that certain beds of undoubted Inferior Oolite and older than the Cornbrash. During the 20 years that succeeded the appearance of Prof. Phillips's work on Yorkshire many important publications, bearing on the subject of the Lower Oolite, occurred both in England and on the Continent; and large collections of fossils were made both from the Oolites of Gloucestershire and Yorkshire, so that there were many facilities for comparing the fauna of the two. The result of this was that in 1850 Dr. Lycett, when examining a small selection of fossils which had been obtained by the Rev. P. B. Brodie from the Lincolnshire Oolite near Grantham, was able to point out that they were of Inferior rather than Great Oolite age.† In the same year appeared the first part of the monograph on the Great Oolite Mollusca in which the authors stated that the Yorkshire shells have a decided Inferior Oolite facies, 'and kept them separate from those of the West of England on account of the doubt existing as to the identity of age of the two deposits. In 1856–8 Oppel identified the Yorkshire beds with the zone of *Ammonites humphriesianus*, therefore placing them below the highest portion of the Inferior Oolite‡; and about the same time a similar conviction was expressed by Lycett.§ In 1859 Wright, in the detailed paper mentioned above, further elaborated these views, which were again confirmed by Lycett in 1861–3 in the Supplementary Monograph to the Great Oolite Mollusca, additional evidence being brought forward on the subject. This was the state of the case at the time that Prof. Judd undertook the working-out of the Lower Oolites in the midland counties; and was able, by carefully tracing out and studying the various subdivisions of the beds in the field, to obtain a surer basis upon which to build a classification of these strata, and more exact knowledge as to the changes produced in them in passing from the west to the northern counties.

Besides discussing in this memoir this all-important question as to the age of the Lincolnshire Oolite and associated beds, the several divisions of the Lias are also worked out, and their position in the palæontological scale shown by reference to the works

* Ann. of Phil., ser. 2, vol. xi. p. 435.

† Ann. Mag. Nat. Hist., ser. 2, vol. vi. p. 256; Proc. Cotteswold Nat. Club, vol. i. p. 52; and Rep. Brit. Assoc. for 1850, Trans. of Sections, p. 74. D'Orbigny also in his "Prodrôme de Paléontologie," published in this year (1850), placed many of the so-called Great Oolite fossils in his Étage Bajocien, or Inferior Oolite.

‡ Die Juraformation, p. 340.

§ The Cotteswold Hills. Handbook Introductory to their Geology and Palæontology.

of Quenstedt and other foreign geologists. Prof. Judd also enters into the physical history and origin of the rocks; showing the relation of the midland district to other areas, and pointing out the more estuarine character of the series as we advance northwards: a fact that was further worked out in his subsequent memoirs on the Jurassic rocks of the east and west coasts of Scotland in 1873 and 1878, which latter have made important additions to our knowledge of the physical history of this period.*

With regard to Yorkshire, however, the most important additions that have been made to your knowledge of the Jurassic rocks are the detailed and elaborate memoirs of Mr. W. H. Hudleston on "the Yorkshire Oolites" and of Messrs. Tate and Blake on "the Yorkshire Lias." The first of these was commenced in 1874 by a description of the Lower Oolites, this was followed in 1876 by an account of the Oxfordian strata, and completed in 1878 by that of the Corallian rocks; the whole being supplemented by two valuable memoirs entitled "Contributions to the Palæontology of the Yorkshire Oolites," describing the Gasteropoda of the Corallian and Lower Oolitic rocks respectively, which appeared between the years 1880 and 1885.† This latter subject is now being more fully elaborated in the Monograph of the Palæontographical Society on the British Jurassic Gasteropoda, commenced in 1887; in which a general sketch is given of the Inferior Oolite and many Yorkshire species are described. Hudleston in these papers, after giving a very accurate account of the stratigraphical and lithological details of the rocks, enters into a careful analysis of their palæontological contents, showing the range of the various genera and species, and pointing out in many cases their relation to similar beds on the Continent. The memoirs on the Gasteropoda help to fill up a blank in our knowledge of the Palæontology of the Yorkshire Oolites; in which, if we except the memoirs on the Echinodermata by Dr. Wright, the Belemnites by Prof. Phillips, and the Trigoniæ by Dr. Lycett, little had been done since the monograph of Morris and Lycett on the univalve and bivalve mollusca.

The appearance of the "Yorkshire Lias" in 1876 was an important event in the knowledge of these rocks. In this work Messrs. Tate and Blake give a most detailed account of the stratigraphy and palæontology of the Lias throughout Yorkshire, pointing out the various horizons or zones into which the formation is capable of division. This subject, which had been commenced by Hunton in the description of a particular section, and by Oppel in a general view of these zones throughout England, is further elaborated by these authors in a series of type sections, the equivalents of which are traced across the county from the coast to the Humber. The work is supplemented by a careful account

* Quart. Journ. Geol. Soc., vol. xxix. p. 97, and vol. xxxiv. p. 660.

† Proc. Geol. Assoc., vol. iii. p. 283; vol. iv. p. 353; vol. v. p. 407; Geol. Mag., dec. ii., vol. vii. pp. 241, 289, 391, 481, 529; vol. viii. pp. 49, 119; vol. ix. pp. 145, 193, 241; dec. iii. vol. i. pp. 49, 107, 145, 193, 241, 293; vol. ii. pp. 49, 121, 151, 201, 252.

of the palæontology of these rocks giving the exact horizon and references of every species, and treating in a scientific manner that which had been done by Simpson in a more popular form. The "Yorkshire Lias" completes the description of the Jurassic rocks begun by Hudleston with the Oolites; and, although we have not in all cases been able to agree with the stratigraphical details, is a most valuable contribution to the study of these formations.

In 1877 the joint memoir of Messrs. Blake and Hudleston on "the Corallian Rocks of England" was published.* This was a further extension of the work commenced by the latter author on the Yorkshire Oolites; the authors show that the whole of the strata between the Oxford and Kimeridge Clays are one continuous formation, and that the Corallian Rocks mark local changes which took place in the nature of these deposits, due to alteration in the physical conditions of the several areas. In the present Memoir we have not hesitated to make use of these important monographs, illustrating our own work by copious extracts from them.

The work thus accomplished for a portion of the Jurassic rocks has been carried by Blake into the higher divisions of the series in the following communications which have been laid before the Geological Society of London:—"the Kimeridge Clay of England" which appeared prior to those just mentioned in 1875†; "the Portland Rocks of England" in 1880‡; and "the Correlation of the Upper Jurassic Rocks of England with those of the Continent" in 1881.§ This latter subject has been further supplemented by Mr. T. Roberts in 1887, who undertook "the Correllation of the Upper Jurassic Rocks of the Swiss Jura with those of England."‖

Since the publication of these papers, apart from those devoted to palæontology, no very important memoirs have appeared on the Jurassic geology of this district, except the recent account of "the Subdivisions of the Speeton Clay," by Mr. G. W. Lamplugh.¶ In this excellent paper a most detailed description is given of the generally obscure section at Speeton; where, the author's observations being carried on over a number of years, he has been enabled to piece together the information gathered from scattered exposures, and so to obtain a more correct appreciation of their meaning. This account, which deals with the whole of the Cretaceous and Jurassic Clays exposed at this place, is, however, of chief importance from the new light thrown upon the junction-beds between these formations—"the Portlandian" of Leckenby and Judd. It is also shown that the true position of these beds had been mistaken, their Jurassic affinity is pointed

* Quart. Journ. Geol. Soc., vol. xxxiii. p. 260.
† *Ibid.*, vol. xxxi. p. 196.
‡ *Ibid.*, vol. xxxvi. p. 189.
§ *Ibid.*, vol. xxxvii. p. 497.
‖ *Ibid.*, vol. xliii. p. 229.
¶ *Ibid.*, vol. xlv. p. 575.

out, and their correlation with beds of other areas is indicated. Simultaneously with the working out of these beds by Mr. Lamplugh, the two eminent Russian geologists, M. Serge Nikitin, of the Geological Survey of Russia, and Prof. A. Pavlow, of the University of Moscow, who have also studied the Speeton section and compared it with the equivalent strata of that country, in a series of communications point out that these junction beds are far more nearly allied to their Volgien supérieur, with which they should be considered as synchronic or homotaxial, than to the true Portlandian of the South of England and France.* It is much to be desired that the study and reconsideration of the position of these beds throughout Northern Europe may be undertaken before long, so that the relations between the Cretaceous and Jurassic strata in this area may be better understood.

Besides these a few minor publications have appeared from time to time, but they are all more or less devoted to special subjects, and therefore have not much influence on the general current of scientific opinion.

That much remains to be worked out is certain, and many intricate problems have yet to be solved before our knowledge of the Jurassic rocks of this county can be said to be anything like complete. In what direction further research is most needed may be a matter of opinion, but it must be admitted that the palæontological branch of the subject is one that urgently requires to be taken up. Much has been done, as we have observed, by Hudleston, Blake, and others, but as yet many classes of the invertebrata are almost untouched, more especially the bivalve mollusca, the crustacea,† and the Oolitic ammonites‡; we can only therefore hope that before long these important branches may be illustrated by further monographs.

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* S. Nikitin, "Les Vestiges de la Période Crétacée dans la Russie centrale," Mém. du Com. Géol. Russ., vol. v., No. 2, 1888; "Quelques excursions dans les Musées et dans les Terrains Mésozoiques de l'Europe Occidentale," Bull. Soc. Géol. Belge, t. iii., p. 29, 1889. A. Pavlow, "Etudes sur les couches Jurassiques et Crétacées de la Russie," 8vo. *Moscow*, and Bull. Soc. Imp. Nat. Moscow, 1889; "Le Néocomien des Montagnes de Worobiewo," 8vo., *Moscow*, 1890. A. Pavlow and G. W. Lamplugh, "Argiles de Speeton et leurs équivalents." 8vo., *Moscow*, 1892.

† Dr. Carter has given some attention to this subject, but has as yet only described a few of the Yorkshire species. *See* Quart. Journ. Geol. Soc., vol. xlii., p. 542.

‡ The Monograph of the Palæontographical Society on the Inferior Oolite Ammonites of the British Islands, by S.S. Buckman, commenced in 1887, has not as yet taken much notice of Yorkshire species.

…RE JURASSIC (and CRE…

W. C. WILLIAMSON. 1837–1842.	Prof. J. F. BLAKE. The Lias conjointly with R. Tate. 1875–1881.	Divisions adopted by the GEOLOGICAL SURVEY. 1880.	
		Alluvium. Boulder Clay.	
		Chalk without Flint Chalk with Flints Lower or Grey Chalk Red Chalk Neocomian Beds	Cretaceous Rocks.
	…pper Kimmeridge Clay …ower Kimmeridge Clay	Kimeridge Clay	Jurassic Rocks.
		Upper Calcareous Grit	
		Upper Limestone	
		Middle Calcareous Grit Lower Limestone	
…xford Clay …elloways Rock		Passage Beds Lower Calcareous Grit Oxford Clay Kellaways Rock	
…ornbrash …pper Sandstone and Shale		Cornbrash Upper Estuarine Series	
…reat or Bath Oolite (part)		Grey Limestone	
…iddle Series …reat or Bath Oolite (part)		Middle Estuarine Series Millepore Bed	
…ower Sandstone and Shale		Lower Estuarine Series, with Eller-Beck Bed and Hydraulic Limestone.	
…nferior Oolite (upper part)		Dogger	
…pper Lias …arlstone …ower Lias	…pper Lias in three zones …iddle Lias in seven zones …ower Lias in five zones	Upper Lias Ironstone Series Sandy Series Lower Lias	

[T]ABLE of FOREIGN

			Brauns, 1869-7 [...] untere, mittlere und obera Jura.		Renevier, 1874. Tableau des Terrains.	
ıd Blaue	ζ	Der Weise Jura.	Étage P[...]ten des Am. gigas	Der oberer Jura.	Portlandien	Portlandien.
			Étage K[...]eridgegeschichte		Kimmeridgien	
					Sequanien	Corallien.
	ε		Étage C[...]ten des Cidaris florigemma oder [...]allen Oolith.		Rauracien	
›änke	δ				Glypticien	
	γ					
	β					Oxfordien.
			Étage O[...] [...]ımer Schichten oder Perarmaten		Argovien Divesien	
	α					
	ζ	Der braune Jura.	Étage C[...]nthone [...]cephalenschichten	Der mittlere Jura.	Kellovien	
	ε					Bathonien.
	δ		Etage B[...]ischen Mergel und Eisenkalke [...]ula echinata, Sow.		Bradfordien	
giganteus	γ				[Vesulien]	
			[...] mit Bel. giganteus		Bajocien	
			Étage B[...]			
zen	β				Aalenien	
	α					
					Opalinien	Supra-Lias ou Toarcien.
	ζ	Der schwarze Jura.	Étage T[...]l mit Am. Germani [...]ɔnienschiefer		Thouarsien	
	ε					
	δ					
			Étage L[...]eenthone [...]ten des Am. Davoei, u. Am. [...]s.	Der untere Jura.	Cymbien	
Belemniten	γ					
			[...]en des Am. Jamesoni			
	β		Étage S[...]en des Am. ziphus		Oxynotien	Lias ou Sinemurien.
	α		[...]schichten [...]enschichten [...]tenschichten		Gryphitien Hettangien	
					Rhætien	

will be shown in a later vo[...]

CHAPTER II

THE LIAS.

General Remarks.

The term "Lias" seems to be a corruption of the word "layers," which was probably a quarryman's designation of these beds, suggested by the regular character of their stratification. We first meet with the word about 1719 in a letter by John Strachey entitled "A curious Description of the Strata observed in the Coal Mines of Mendip in Somersetshire;" wherein he says, "Under which [the soil] are Quarries of *Lyas*, in several Beds, to about eight or ten Feet deep, and six Feet under that thro' yellowish *Loom* you have a blue Clay enclinable to *Marle*, which is about a Yard thick."* The word is also used by Smith in 1815, in the memoir in explanation of his map; but he only applied it to the lower beds, a good deal of confusion existing at that time as to the proper correlation of the upper part of the formation. Subsequently the term appears to have come into more general use.

The Lias is usually separated into the three main divisions of Upper, Middle, and Lower; but these are capable of further subdivision into numerous bands or beds distinguished by some characteristic fossil, usually an ammonite. These beds or zones as they are called are of great assistance in correlating the various horizons of the Lias of the British Islands with those of the Continent, and also in small or obscure exposures in fixing the exact position of any particular bed. There is a good deal of difference of opinion as to the value of palæontological zones, and much error exists as to their exact significance. A palæontological zone does not constitute a hard and fast line, as has been supposed by some, to which the characteristic ammonite or whatever fossil may be taken as the type is restricted, but merely implies that that species is more abundant there than elsewhere, and that the other fossils with which it is associated constitute a general assemblage which marks out that particular horizon as sufficiently distinct from the rest of the formation.†

The Yorkshire Lias is capable of division into from 12 to 15 of these zones, but there is some difference of opinion as to the grouping of these into the three main divisions of Upper, Middle, and Lower. This arises from the fact that the most marked changes in the petrological character of the rocks do not agree with the greatest breaks in the life of the period, and consequently

* Phil. Trans., 1719, vol. xxx., p. 968.

† *See also* Judd, Geology of Rutland, &c. (Geol. Survey), p. 48; Tate, Quart. Journ. Geol. Soc., vol. xxiii. p. 3[illegible]; and Woodward, Proc. Geol. Assoc., vol. xii., 1892, p. 295.

the most striking physical features do not coincide with the main palæontological divisions. Thus many authors include the whole of the beds between the zone of *Am. oxynotus* and *Am. serpentinus* in the Middle Lias, drawing its boundaries at the base of the *Am. Jamesoni* zone, and at the top of the *Am. annulatus* zone, where the principal change in the character of the fauna takes place. But the greatest breaks in mineral character occur at the top of the Ironstone Series, and at the base of the Sandy Series. Between these points, which include the zones of *Am. spinatus*, *Am. margaritatus*, and the upper part of *Am. capricornus*, the strata consist of ironstones and micaceous sandstones having a marked contrast to the shales above and below. Inland they form a more or less prominent feature, which stands out from the softer strata and can be easily followed along the outcrop; while it is impossible, except on the coast, where there are clear and frequent sections, to trace the junction between the zones of *Am. Jamesoni* and *Am. oxynotus*, or between that of *Am. serpentinus* and *Am. annulatus*, which are in the midst of shales. Consequently the top of the Ironstone Series and the base of the Sandy Series are the only lines of boundary that can be mapped with any accuracy, and for this reason are adopted by the Geological Survey.

The following table shows the zones into which the Lias of Yorkshire is capable of subdivision compared with the equivalent divisions of different authors, the thick lines indicating the main groups adopted by each.

We also give a second table showing the divisions adopted before this system of classification came into vogue, founded mainly on petrological or topographical considerations.

In describing the general development of the Lias it is more convenient as we have observed to group the several zones in the three main divisions of Upper, Middle, and Lower, and trace the outcrop of these from the coast inland. Each of these larger sub-divisions has a distinct physical aspect, that even in the absence of sections is readily followed across the country, either by the change in contour or the nature of the soil; which it is not possible to do with the separate zones.

	Lower Lias.†	Middle Lias.	Upper Lias.	Lower Oolite.	Di

* Thes

† The

beds (Wh

	Geological Survey.	1815-1821.		W. Phillips, 1822.	1822.	1829.	[illegible]	[illegible] and Blake, 1876.	
Lower Oolite.	Blea Wyke Beds.							Blea Wyke Beds.	Inferior Oolite.
Upper Lias.	Alum Shale.	Alum Shale, but wrongly identified with the Oxford Clay.			Main bed of Alum Shale.	Alum Shale.	Alum Shale.	Zone of *Ammonites jurensis*. Zone of *A. communis*.	Upper Lias.
	Jet Rock.				Sandsend Beds.	Jet Rock. Hard Shale.	Jet Rock.	Zone of *A. serpentinus*.	
	Grey Shale.				Hard compact Alum Shale.	Soft Shale.		Zone of *A. annulatus*.	Middle Lias.
Middle Lias.	Ironstone Series.	Marlstone	Sub-divisions not identified in Yorkshire.	Great argillaceo-calcareous formation of the Lias and Lias Marle.	Kettleness Beds.	Ironstone Series.	Ironstone Series.	Zone of *A. spinatus*.	
	Sandy Series.				Staiths Beds.	Marlstone Series.	Sandy and Micaceous Beds.	Zone of *A. margaritatus* } In two divisions.	
Lower Lias.	Upper Series with ron-stone nodules.	Blue Marl					Ironstone Series of the Lower Lias.	Zone of *A. capricornus*. Zone of *A. Jamesoni*. Region of *A. armatus*.	
		Blue Lias			Lowest Alum Shale.	Lower Lias Shale.		Zone of *A. oxynotus*.	Lower Lias.
	Lower Series with sandy and marly bands.	White Lias					Indurated Bands of the Lower Lias.	Zone of *A. Bucklandi* } In three divisions. Zone of *A. angulatus*. Zone of *A. planorbis*.	
	Rhætic or Penarth Beds.							*Avicula contorta* Beds.	Rhætic.

* This column, although not founded on petrological character, is inserted for comparison with the palæontological divisions.

LOWER LIAS.

Account of the Zones in the Lower Lias, as they are exhibited in the Yorkshire Cliffs.

It being chiefly on the coast that the several zones of the Lias are well seen and can be easily studied, we propose to take that section first, and trace out each of these subdivisions separately, merely alluding to the other localities when the sections are sufficiently clear to enable them to be made out; and subsequently to treat of their inland development.

THE ZONE OF AMMONITES PLANORBIS.

Synonyms and Foreign Equivalents:—"Blue Lias" (part), W. Smith, Memoir to the Map, p. 47, 1815; "Die Schichten des *Ammonites planorbis*," Oppel, Juraformation, p. 24, 1856; "Psilonotenbank," Quenstedt, Der Jura, p. 40, 1858; "Infra-Lias (part), Lumachelles à *Ammonites planorbis, A. tortilis* et *A. Burgundiæ*," Martin, Pal. stratigr. de l'Infra-lias de la Côte d'Or, p. 38, 1860; "Hettangien" (part), Renevier. Notices Géologiques et Paléontologiques, sur les Alpes Vaudoises, Bull. Soc. Vaud. Sc. Nat., vol. viii., p. 89, 1864; "Zone of *Ammonites planorbis*," Wright, Quart. Journ. Geol. Soc., vol. xvi., p. 389, 1864; "Psilonoten-schichten," Brauns, Die untere Jura, p. 55, 1871; "Zone of *Aegoceras planorbis*", Wright, Lias Am., p. 14, 1878.

This, the lowest zone of the Lias, immediately succeeds the Rhætic Beds, and in fact the passage from one into the other is so gradual that at first sight it is not easy to say where to draw the line. In the south of England the characteristic ammonite is found principally in the upper part of the zone; below this are a series of limestones and shales in which *Ostrea liassica* is very abundant, while locally these beds also yield the remains of Enaliosauria, and have been termed the Saurian Beds. In Yorkshire from the absence of reptilia, the lower beds are not nearly so strongly marked, and it becomes a matter of some doubt as to how much should be included with the Lias. In the neighbourhood of Northallerton, where the Rhætic Beds are best exposed, the dark pyritous shales with *Avicula contorta* are overlaid by whitish argillaceous limestone and shales which we have included in the Rhætic Series. Above this there are about 15 feet of finely laminated shale with impressions of *Pleuromya* and *Cardium*, which are capped by shales and thin limestones containing *Pleuromya crowcombeia, Cardium phillipianum*, and *Ostrea liassica* constituting the lowest beds of the Lias.* These are succeeded by shales and bands of limestone in which *Ostrea liassica* is the predominant and distinguishing fossil, while above these are alternations of clays or shale and thinner beds of limestone in which the characteristic ammonite has been found.

By far the best sections in this horizon are in South Yorkshire, so that it will be necessary to refer to these in order to understand the less complete exposures in the northern part of the county. That this zone exists on the coast is known from the

* *See* Memoirs of the Geological Survey, Expl. of 96 N.W. p. 13.

fact that large blocks, which are full of the characteristic ammonite, are frequently washed up by the waves in Robin Hood's Bay, although the beds themselves nowhere come above low-water mark. These boulders consist of light-coloured limestone in which the ammonite often occurs in a semi-transparent state, so that its structure is beautifully displayed.

From the spoil-heap of a pit which was sunk in search of coal near Coatham, Messrs. Tate and Blake have obtained *Ammonites planorbis*, but associated with a fauna, the facies of which indicates the higher zone of *Am. angulatus*, so that it is not very clear whether the two zones are really distinct. These authors give the following list of fossils from this locality.*

From the Limestone:

Ammonites Johnstoni.	Pecten lunularis.
—— planorbis.	—— textorius.
Eucyclus elegans.	Modiola lævis.
Cerithium tenuicostatum.	Pinna Hartmanni.
Lima gigantea.	Pleuromya galathea.
—— pectinoides.	Pentacrinus psilonoti.
Ostrea arcuata (small).	Hemipedina Tomesii.
—— liassica.	

From the Shale:

Cardinia ovalis.	Astarte obsoleta.
—— Listeri.	Unicardium cardioides.
Nucula navis.	Pholadomya Fraasii.
Astarte cingulata.	Rhynchonella plicatissima.

From the Gypsum Pit at Eston† fragments of *Pleuromya*-limestone were obtained as well as black shales with *Ammonites planorbis*, but there is not sufficient evidence to fix the exact position of the beds. In the neighbourhood of Northallerton the lower or non-ammonitiferous portion of this zone is well exposed, where it forms the upper part of the low hill facing that town. Fragments of *Pleuromya*-limestone and of the *Ostrea-liassica*-beds above are frequently met with along the brow of the hill, and sections in them are seen at Foxton, Hallikeld Farm, Dibdale, and Crosby Cote. In South Yorkshire the beds composing this zone are much clearer, a good series of sections being exposed in the pits that have been opened out along the fine escarpment formed by the lower part of the Lias in the neighbourhood of Cliff to the south of Market Weighton. There are several of these pits, the sections in which have been ably described by Prof. Blake, first in his paper on the Infra-lias of South Yorkshire,‡ and subsequently in the larger work on the Yorkshire Lias.§ From the latter description we take the following account of the beds seen in pit No. 3, close to the village of North Cliff, which affords the most complete section. This pit has now been continued in a deep road-cutting to the farm at the top of the hill, and the sides sloped down, which has considerably obscured the exposure.

* The Yorkshire Lias, p. 44.
† *Ibid.* p. 31; and Memoirs of the Geological Survey, Expl. of 104 S.W. p. 5.
‡ Quart. Journ. Geol. Soc., vol. xxviii. p. 132 *et seq.*
§ Loc. cit., p. 38 *et seq.*

Section at North Cliff, Market Weighton.

No.	Petrology.	Thickness. Ft. In.	Organic Remains.
—	Surface soil	2 3	*Ammonites Johnstoni, Cardinia Listeri, Ostrea liassica, Lima gigantea.*
—	Rubbly stone	1 6	
—	Rough rubbly clay	1 4	
—	Rubbly stone	0 8	
—	Probable base of *angulatus*-beds.	3 2	
1	Rough yellow clay	3 2	*Pentacrinites.*
2	Stone with many broken shells.	0 8	
3	Clay with many broken shells.	1 0	
4	Stone with many broken shells.	1 4	Wood.
5	Bluer clay	2 2	
6	Double sandy stone	0 8	*Lima gigantea, Modiola minima.*
7	Blue clay	0 2	*Am. Johnstoni, Ostrea liassica, O. irregularis, Avicula inæquivalvis.*
8	Sandy broken stone	3 7	Oysters.
9	Blue clay	5 6	*Protocardium philippianum, Ostrea liassica.*
10	Stone	0 5	*Lima gigantea.*
11	Blue clay	3 7	*Cidaris Edwardsii, Dapedius* (tooth).
12	Stone	0 10	*Modiola minima.*
13	Clay with scattered septarian nodules.	2 0	*Am. Johnstoni, Hybodus minor.*
14	Stone	0 5	
15	Blue clay with few fossils	9 0	*Am. planorbis* (compressed) *Protocardium philippianum, Ichthyosaurus*, sp. (vertebra).
16	Rubbly soft stone	0 4	
17	Rough yellow clay	0 4	
18	Rubbly stone	0 4	
19	Rough clay	0 5	
	(Base of the first section).		
20	Double oyster-band	0 6	*Ostrea liassica, Protocardium philippianum, Macrodon hettangiensis, Nautilus striatus.*
21	Clay	0 2	
22	Broken oyster-band	0 5	
23	Clay lightest at the top	0 8	*Ostrea liassica, Monotis fallax.*
24	Rubbly stone	0 2	
	(Base of the oyster-beds, 1ft. 11in.).		
25	Clay	0 10	
26	Light sandy rubbly clay	0 4	*Pleuromya crowcombeia, Modiola minima, Protocardium philippianum.*
27	Clay with irregular bands of limestone (*Pleuromya* limestone).	1 6	
28	Light sandy clay	2 6	
29	Clay	2 4	
30	Soft white stone	0 3	
31	Clay	1 8	
32	Soft white stone	0 3	
33	Variable clay	0 6	
34	Blue clay	3 4	
35	Whitish sandy stone	0 2	
36	Clay to the base	2 0	
	Total of *planorbis*-beds	55 4	

There are several other pits along this escarpment which give sections of higher and also rather lower beds in the series, but this is the most complete of any of them.

The following list of fossils are recorded from the zone of *Am. planorbis* in Yorkshire :—*

Fossils from the Zone of Am. planorbis.

ECHINODERMATA.

Cidaris Edwardsii, *Wright.*
Hemipedina Tomesii, *Wright.*
Pentacrinus psilonoti, *Quenst.*

CRUSTACEA.

Bairdia liassica, *Brodie.*
Cythere Blakei, *Jones.*
Cythere Moorei, *Jones.*
—— Terquemia, *Jones.*

INSECTA.

Chauliodites minor, *Blake.*

LAMELLIBRANCHIATA.

Avicula fallax, *Pflücker.*
Lima gigantea, *Sow.*
Ostrea liassica, *Strickland.*
Pecten æqualis, *Quenst.*
—— pollux, *d'Orb.*
Astarte obsoleta, *Dunker.*
Cardinia ovalis, *Stutchbury.*
Cardium phillipianum, *Dunker.*
Macrodon hettangiensis, *Terquem.*
Modiola lævis, *Sow.*
—— minima, *Sow.*
Pleuromya crowcombeia, *Moore.*

GASTEROPODA.

Actæonina fragilis, *Dunker.*
Discohelix liasinus, *Dunker.*
Pleurotomaria concava, *Martin.*
Turbo tenuis, *Terquem.*

CEPHALOPODA.

Ammonites Johnstonii, *Sow.*
—— planorbis, *Sow.*
Nautilus striatus, *Sow.*

PISCES.

Dapedius, sp.
Hybodus minor, *Ag.*

REPTILIA.

Ichthyosaurus, sp.

ZONE OF AMMONITES ANGULATUS.

Synonyms and Foreign Equivalents :—"Gelber unterer Liassandstein," Mandelsloh, Geogn. Profile der schwäb. Alp., p. 28, 1834; "Unterer Lias-Sandstein (Quader- Schilf- oder Luxemberger Sandstein)" (part) Römer, Versteinerungen, p. 3, 1836; "Grés infraliasique" (part), Dufrenoy et de Beaumont, Exp. de la carte géol. de France, vol. ii., p. 157, 1848; "Grés liasique, grés de Hettange," Terquem, Pal. du Dep. de la Moselle, p. 11, 1855; "Die Schichten des *Ammonites angulatus*," Oppel, Juraformation, p. 28, 1856; "Malmstein, Thalassitenbänke oder Angulatenschichten," Quenstedt, Der Jura, p. 52, 1858; "Zone à *Ammonites Moreanus*: Calcaire marneux à *Am. angulatus* et *Am. liassicus*," Martin, Pal. stratigr. de l'Infra-Lias du Dép. de la Côte d'Or, Mem. Soc. Geol. de Fr., p. 38, 1860; "Angulatenschichten," Seebach, Der Hannoversche Jura, p. 17, 1864; "Hettangien" (part), Renevier, Bull. Soc. Vaud. Sc. Nat., vol. viii., p. 89, 1864; "Zone d'*A. angulatus*," Dumortier, Dép. Jurassique de Bassin de Rhône, p. 100, 1864; "Zone of *Ammonites angulatus*," Tate and Blake, Yorkshire Lias, p. 46, 1876; "Zone of *Aegoceras angulatum*," Wright, Lias Ammonites, p. 27, 1878.

* This and the other lists of fossils in the several zones of the Lias are taken chiefly from those published by Messrs. Tate and Blake, with a few alterations and additions.

The *angulatus*-zone is not very distinctly represented, either in the south of England or in the Midland counties, but after crossing the Humber this division becomes more important, the lower portion of the series being well seen at Cliff to the south of Market Weighton; while at Redcar at the northern extremity of the county the upper beds are exposed and their relation to the *Bucklandi*-beds is well shown. On the Continent this zone contains a very abundant fauna, which constitutes the upper part of the Hettangien or Infra-lias of French authors. This is the lowest zone that appears on the coast, and even there only at Redcar. Here, on the shore at low-water mark opposite the Battery these beds are brought up between the *Bucklandi*-beds for a distance of about 400 yards, and are sometimes well exposed. Messrs. Tate and Blake have given this section in great detail, from which we take the following account:—*

Section of the Angulatus-*beds at Redcar.*

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
	Base of lowest scar of the *Bucklandi* zone.	—	*Ammonites Conybeari, Lima gigantea, Pentacrinus.*
1	Blue shale with a line of *Am. Conybeari* at a depth of 1 foot.	2 8	*Cardinia Listeri, Gryphæa arcuata, Lucina limbata, Pentacrinus.*
2	Indurated shale 5 inches, earth limestone 1 inch.	2 6	*Am. angulatus* and small *Gryphæa, Unicardium cardioides.*
3	Blue shale - -		*Am. angulatus.*
4	Friable shale, an oyster band and irregular limestone nodules 1½ inch.	0 7	*Am. angulatus, Pleurotomaria similis, Dentalium etalense, Astarte Oppeli, Lima gigantea, Cardinia Listeri, Pleuromya crassa, Serpula socialis,* &c.
5	Blue shale - -	1 0	Large *Am. angulatus* and scattered *Gryphæa.*
6	Friable shale with oysters chiefly (2 inches).	0 5	*Am. angulatus, Cardita Heberti, Lucina limbata, Plicatula liasina, Terquemia arietis, Perna infraliassica, Rhynchonella plicatissima, Montlivaltia polymorpha.*
7	Blue shale - -		
8	Band of small *Gryphæa* ½ inch.	3 0	*Am. angulatus, Plicatula liasina.*
9	Blue shale - -		
10	Shell band and shelly limestone, 1½ inch. Blue shale with irregular doggers, 5 inches.	6 4	*Am. angulatus, Eucyclus elegans, Astarte obsoleta.*
11	Blue shale - -		*Am. angulatus, Eucyclus acuminatus.*
12	Shelly limestones sometimes encrinital, mixed with shale, 2½ inches.	2 8	
13	Blue shale - -		

* Loc. cit., p. 48.

No.	Petrology.	Thickness. Ft. In.	Organic Remains.
14	"Coral bed," a friable shale with small pebble-like concretions at the top, very fossiliferous, 2½ inches.		*Am. angulatus*, *Astarte Oppeli*, *Cardita Heberti*, *Plicatula liasina*, *Pleurotomaria similis*, *Montlivaltia Haimei*, *Serpula socialis*, *Waldheimia sarthacensis*, *&c.*
15	Depressed irregular limestone doggers, 1½ inches.	2 0 (14–16)	
16	Shale with scattered *Gryphæa arcuata* of moderate size.		*Am. angulatus* (large).
17	Earthy subcrystalline limestone, 1 inch.	1 2 (17–18)	Large *Am. angulatus*.
18	Black smooth shale -		
19	Friable shale - - / Oyster-band - -	0 6	
20	Smooth shale - -	0 6 (20–21)	
21	Siliceous limestone, ½ inch / Smooth shale - -		
22	Irregular depressed limestone doggers. / Thin shell-limestone -	8 2 (22–23)	*Lima gigantea*, of large size.
23	Friable shale - / Smooth shale, 9 inches -		*Am. angulatus* very large.
24	Earthy limestone or doggers.	0 2	*Cardinia ovalis*.
25	Smooth shale - -	1 0	
26	Blue siliceous limestone -	0 1	*Ostrea ungula*, *Dentalium etalense*.
27	Friable shale - -	0 8	*Am. angulatus*.
28	Siliceous limestone, or rather a band of depressed doggers fused together.	0 2	
29	Friable shale - -	1 5	*Am. angulatus*.
		30 0	

In South Yorkshire the *angulatus*-beds are seen in several small sections particularly in the numerous pits to the south of Market Weighton, where they form the upper part of the great bank running to North Cave; but, as it is only the lower portion of the zone that is exposed, there is no complete section that can be measured.*

Fossils from the Zone of Am. angulatus.

Plantæ.

Alethopteris sp.

Cœlenterata.

Montlivaltia Haimei, *Chap. & Dew.*
—— polymorpha, *Terquem.*
Septastræa excavata, *Fromentel.*

Echinodermata.

Cidaris Edwardsii, *Wright.*
Hemipedina Tomesii, *Wright.*
Pentacrinus basaltiformis, *Miller.*
—— psilonoti, *Quenst.*

* Page 33.

ANNELIDA.

Ditrupa capitata, *Phil.*
—— globiceps, *Quenst.*
Galeolaria (Serpula) socialis, *Goldf.*
Serpula deplexa, *Bean.*
—— limax, *Goldf.*
—— plicatilis, *Goldf*

CRUSTACEA.

Bairdia elongata, *Blake.*
—— lacryma, *Blake.*
—— liassica, *Brodie.*
—— redcarensis, *Blake.*
Cythere arcæformis, *Blake.*
Cythere Blakei, *Jones.*
—— redcarensis, *Blake.*
Cytherella circumscripta, *Blake.*
—— paupercula, *Blake.*
Polycope cerasia, *Blake.*

BRACHIOPODA.

Rhynchonella calcicosta, *Quenst.*
Spiriferina rostrata, *Schlot.*
Waldheimia perforata, *Piette.*

LAMELLIBRANCHIATA.

Anomia alpina, *Winkler.*
—— striatula, *Oppel.*
Avicula Pattersoni, *Tate.*
Lima gigantea, *Sow.*
—— hettangiensis, *Terquem.*
—— pectinoides, *Sow.*
—— succincta, *Schlot.*
—— Terquemi, *Tate.*
Limea blakeana, *Tate.*
Gryphæa (Ostrea) arcuata, *Lam.*
Ostrea semiplicata, *Münster.*
—— ungula, *Münster.*
Pecten calvus, *Goldf.*
—— punctatissimus, *Quenst.*
—— textilis, *Münster.*
—— textorius, *Schlot.*
Perna infraliassica, *Quenst.*
Pinna Hartmanni, *Ziet.*
Plicatula liasina, *Terquem.*
Astarte cingulata, *Terquem.*
—— obsoleta, *Dunker.*
—— Oppeli, *Andler.*
Cardinia crassiuscula, *Sow.*
—— Deshayesi, *Terquem.*
—— Desoudini, *Terquem.*
—— Listeri, *Sow.*
Cardinia ovalis, *Stutch.*
Cardita Heberti, *Terquem.*
Cardium phillipianum, *Dunker.*
Ceromya gibbosa, *Etheridge.*
Gresslya galathea, *Ag.*
Hippopodium ponderosum, *Sow.*
Leda galathea, *d'Orb.*
—— Renevieri, *Oppel.*
—— texturata, *Terquem.*
—— v-scripta, *Tate.*
Lucina limbata, *Terquem.*
Macrodon hettangiensis, *Terquem.*
—— naviculus, *Terquem.*
—— pullus, *Terquem.*
Modiola hillana, *Sow.*
—— hillanoides. *Chap. & Dew.*
—— lævis, *Sow.*
Myoconcha inclusa, *Terquem.*
—— psilonoti, *Quenst.*
Nucula navis, *Piette.*
Pholadomya Fraasii, *Oppel.*
—— glabra, *Ag.*
Pleuromya liasina, *Schüb.*
Saxicava arenicola, *Terquem.*
Unicardium cardioides, *Phil.*

SCAPHOPODA.

Dentalium etalense, *Terquem.*
Dentalium limatulum, *Tate.*

GASTEROPODA.

Actæonina fragilis, *Dunker.*
Cerithium gratum, *Terquem.*
—— semele, *d'Orb.*
—— spiratum, *Moore.*
Chemnitzia transversa, *Blake.*
—— unicingulata, *Terquem.*
Cryptænia nucleus, *Terquem.*
—— rotellæformis, *Dunker.*
—— solarioides, *Sow.*
Discohelix semiclausus, *Tate.*
—— striatus, *Piette.*
Eucyclus acuminatus, *Chap. & Dew.*
Eucyclus elegans, *Münster.*
Littorina semiornata?, *Münster.*
Phasianella morencyana, *Piette.*
Pitonillus sordidus, *Tate.*
Pleurotomaria anglica, *Sow.* (similis, *Auct.*).
—— obesula, *Tate.*
—— tectaria, *Tate.*
Turbo Philemon, *d'Orb.*
—— solarium, *Piette.*
Turritella Dunkeri, *Terquem.*

CEPHALOPODA.

Ammonites angulatus, *Schlot.*	Ammonites longipontinus, *Oppel.*
—— Conybeari, *Sow.*	—— nanus ?, *Martin.*
—— Johnstonii, *Sow.*	Belemnites infundibulum, *Phil.*
—— laqueolus, *Schlön.*	Nautilus striatus, *Sow.*

PISCES.

Acrodus minimus, *Ag.*	Hybodus minor, *Ag.*

THE ZONE OF AMMONITES BUCKLANDI.

Synonyms and Foreign Equivalents:—"Blue Lias" (part), W. Smith, Memoir to the Map, 1815; "Gryphitenkalk," Stahl, Corresp. Würtemb. landw. Vereins, 1824; "Gryphitenkalkstein," Alberti, Die Gebirge des K. Würtemb., p. 121, 1826; "Calcaire Marneux à *Gryphæa arcuata*," Brongniart, Tableau des Terrains, p. 238, 1829; "Calcaire à Gryphites" (part), Dufrenoy et de Beaumont, Mém. Soc. Géol. de Fr., p. 196, 1830; "Liaskalk," Mandelsloh, Geogn. Profile der schwäb. Alp, p. 28, 1834; "Grés de Luxembourg" (upper part), Omalius d'Halloy, Élém. de Géol., p. 375, 1835; "Sinemurien ou Lias inférieur" (part), d'Orbigny, Terrains Jurassique, p. 604, 1842; "Arcuatenkalk," Quenstedt, Deutsch. Geol. Gesellschaft, t. 16, 1853; "Die Schichten des *Ammonites Bucklandi*," Oppel, Juraformation, p. 35, 1856; "Arietenkalke," Quenstedt, Der Jura, p. 64, 1858; "Zone of *Ammonites Bucklandi*," Wright, "Quart. Journ. Geol. Soc.," vol. xvi., p. 398, 1860; "Marnes et calc-marneux à *Am. bisulcatus*," Martin, Pal. stratigr. de l'Infra-lias," 1860; "Die Arietenschichten," Brauns, Der untere Jura, p. 78, 1871; "Zone of *Arietites Bucklandi*," Wright, Lias Ammonites, p. 35, 1878.

This is the best known and most important subdivision of the Lower Lias. It is easily recognized by the presence of the group of Arietites or sulcated Ammonites, *Am. Bucklandi*, *Am. bisulcatus*, *Am. Conybeari*, and *Am. Turneri*, as well as by the abundance of *Lima gigantea* and *Gryphæa arcuata*, which also characterize these beds. Of these Ammonites *Am. Conybeari* is restricted to the lower portion, while *Am. Turneri* and *Am. semicostatus* mark the upper part. These upper beds form a well-marked division in the South of England, which Dr. Wright has described as the zone of *Am. Turneri*. This horizon is called by Oppel the *Tuberculatus*-bed, and separated by him from the rest of the *Bucklandi*-beds, but Messrs. Tate and Blake do not consider that there is sufficient distinction in the fauna of the Yorkshire area to justify this division.

The *Bucklandi*-beds consist principally of shales with thin bands of rubbly limestone, which latter are crowded with *Lima gigantea* and *Gryphæa arcuata* (*G. incurva*), so that they are often called either "Lima beds" or "Gryphite limestone"; this oyster being quite as common in this division as *Ostrea liassica* is in the lowest or zone of *Am. planorbis*. There are two good exposures of these beds on the Coast, the one at Robin Hood's Bay, showing the upper part of the series, the other at Redcar, which is more complete, showing the lower beds and their relations with the zone of *Am. angulatus*.

The following section is given by Messrs. Tate and Blake of these beds in Robin Hood's Bay. As they occur here only on

the shore, where they form more or less sloping scars, it is not easy to measure the exact thickness of the beds; those marked (*e*) are therefore only estimated:—

Section of the Bucklandi-*beds, Robin Hood's Bay.*

No.	Petrology.	Thickness.	Organic Remains.
	Blue shale with *A. planicosta* forming the base of the *oxynotus*-beds.	Ft. In. 3 6 (*e*)	
1	Indurated calcareo-argillaceous band, rubbly, speckled, brownish.	0 2	
2	Blue shale harder at the top, with oysters in nests (forming the first broad scar).	5 0 (*e*)	*Am. Turneri, Belemnites acutus, Monotis inæquivalvis, Gryphæa arcuata, Cerithium, Lucina limbata, Pholadomya glabra, Pleuromya* sp. *Modiola lævis, Leda galathea, L. Renevieri, Hippopodium ponderosum, Perna infraliassica.*
3	Blue limestone formed of comminuted shells.	0 3	*Pecten textorius.*
4	Blackish blue crumbly shale with two harder bands in the middle.	2 6 (*e*)	*Gryphæa arcuata, Cardinia hybrida, Modiola lævis, Pleuromya, Nucula navis, Lucina limbata, Hippopodium ponderosum, Pecten calvus, Am. Turneri.*
5	Rubbly indurated band, speckled brown.	0 2	
6	Soft shale, crumbly, not very fossiliferous.	0 8	
7	Calcareous rough shale -	0 8	*Modiola lævis.*
8	Blue shale, papery, with nodules.	4 6 (*e*)	*Am. Turneri, Modiola lævis, Lucina limbata, Cardium oxynoti.*
9	Hard shell-limestone comminuted, pyritous in middle.	0 6	*Gryphæa arcuata, Pecten textorius.*
10	Blue black shales, with oyster layers, papery.	2 8 (*e*)	*Am. semicostatus, Lucina limbata Cardium oxynoti, Modiola lævis, Cerithium* sp., *Leda galathea, Pecten textorius, Leda Renevieri.*
11	Hard earthy not pyritous shell-limestone.	0 2	*Lucina limbata.*
12	Dark crumbly shale -	1 0 (*e*)	*Cardium oxynoti, Lucina limbata, Modiola lævis. Cerithium* sp., *Pleuromya* (cf. *elongata*).
13	Shell limestone very pyritous.	0 1	*G. arcuata, Lucina limbata.*
14	Thin-splitting blue shale with doggers.	0 8 (*e*)	*Pecten textorius.*
15	Shell limestone - -	0 1	*Lucina limbata, Leda galathea.*
16	Blue shale with dogger near the top, with irregular shell-bands.	3 0 (*e*)	*Am. semicostatus, Monotis inæquivalvis, Leda Renevieri, Dentalium etalense, Cardium oxynoti, Leda galathea, Pecten calvus, Pleuromya* (cf. *elongata*), *Lucina limbata.*
17	Red ironstone dogger, blue inside.	0 1	Wood, *Dentalium etalense.*
18	Brown oyster-band, with calcareous crystals in joints.	0 4	*G. arcuata, Pecten Thiollieri, Ichthyosaurus.*

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
19	Blue-black shales with septaria.	1 4 (*e*)	*Lucina limbata, Gryphæa arcuata, Lima hettangiensis, Cerithium* sp., *Leda galathea, Leda Renevieri, Cardium oxynoti, Am. semicostatus, Aptychus*, Wood.
20	Shell-limestone - -	0 1	*Lucina limbata, Pecten Thiollieri, G. arcuata, Belemnites acutus.*
21	Shale with red iron-band, in parts with fucoids.	3 6 (*e*)	*Ditrypa* sp., *Lucina limbata.*

Below this are other bands of rock, but they are so near the level of the lowest spring tides that they are inaccessible or at any rate their thickness cannot be estimated with any accuracy.

North of Robin Hood's Bay the *Bucklandi*-beds do not come above the level of the sea till we reach the neighbourhood of Redcar, where on the shore, when bared of sand, these beds are admirably shown. This section, which we give below, has been very carefully worked out by Messrs. Tate and Blake, who have shown that it is capable of separation into three series based partly on the palæontology and partly on the petrological character of each division.

Section of the Bucklandi-*beds, Redcar Scars.*

	No.	Petrology.	Thickness.	Organic Remains.
			Ft. In.	
		Calcareous shale representing the *oxynotus*-beds.		
Upper Bucklandi Beds, 66 ft. 10 in.	1	Calcareous shale -	10 0	*Am. semicostatus, Gryphæa arcuata.*
	2	Calcareous shale -	8 0	
	3	Calcareous shale with limestone nodules and oyster bed.	1 0	*Am. semicostatus, Pecten calvus, P. Thiollieri, Monotis inæquivalvis, Gryphæa arcuata.*
	4	Calcareous and friable shales.	4 0	*Am. Turneri, Pecten Thiollieri, Gryphæa arcuata.*
	5	Indurated grey shales -	4 0	
	6	Soft blue shales; black limestone nodules at the base.	16 6	*Am. Turneri, Am. bisulcatus, Belemnites infundibulum, Cardinia Listeri* et var. *hybrida, C. concinna, Lima gigantea, Lima succincta, Hippopodium, Pleuromya galathea, Monotis inæquivalvis, Pecten textorius, Gryphæa arcuata.*
	7	Friable sandy shales		
	8	Indurated shales - -	3 6	*Am. Turneri, Am. bisulcatus, Lima gigantea, Cardinia Listeri.*
	9	Smooth blue shale with small cylindrical nodules of black limestone.	11 0	*Am. bisulcatus, Am. Scipionianus* (small).

No.	Petrology.	Thickness. Ft. In.	Organic Remains.
10	Friable shale with black limestone nodules.	3 9	*Ichthyosaurus*, *Acrodus nobilis*, *Am. Bucklandi*, *Am. Sauzeanus*, *Belemnites acutus*, *Gervillia Hagenovii* *Cardinia Listeri*, *Spiriferina Walcotti*.
11	Hard calcareous shales and oyster-band.		
12	Oyster band and earthy limestone.	1 3	
13	Calcareous shale with nodules.	1 9	*Am. Bucklandi*, *Am. Sauzeanus* (common and large), *Monotis inæquivalvis*.
14	Soft shale - -	0 6	*Am. Sauzeanus*.
15	Limestone - -	0 8	
16	Oyster-band - -	0 11	
17	Shaly limestone - -		
18	Hard calcareous shale -		
19	Friable shale - -	1 0	
20	Oyster-band - -	0 3	
21	Hard shale with black limestone nodules.	0 4	
22	Friable shale - -	0 10	
23	Shale - - -	1 10	
24	Limestone - -	0 6	
25	Soft shale - -	0 5	
26	Oyster-band - -	0 0½	*Gryphæa arcuata*.
27	Soft shale - -	0 8	
28	Shale with nodules -	0 10	
29	Limestone - -	0 1½	*Am. Bucklandi*, *Gryphæa arcuata*.
30	Hard shale - -	3 6	
31	Earthy limestone mixed with shale.	0 9	
32	Friable shale - -	3 0	*Am. bisulcatus*.
33	Soft shale - -	12 0	*Am. bisulcatus*, *Am. Charmassei*, large *Cardinia concinna*, *Gryphæa arcuata*, *Lima limbata*, *Hippopodium*, *Myoconcha*, *Pecten textorius*, *Cardinia concinna* (small).
34	Oyster-bed, 1 inch -	9 0	
35	Soft shale with nodules -		
36	Oyster-bed, 1 inch -		
37	Soft shale - -		
38	Oyster-bed, 1 inch -		
39	Stiff blue shale - -		
40	Oyster-bed in friable shale	0 3	*G. arcuata*, *Monotis inæquivalvis*, *Cardinia hybrida*, *Hippopodium*, *Macrodon hettangiensis*, *Mytilus hillanoides*, *Cidaris Edwardsii*.
41	Stiff blue shale - -	1 0	*Monotis*, *Mytilus hillanoides*.
42	Shale with black limestone nodules.	0 2	
43	*Cardinia*-bank - -	0 3	A dense mass of *Cardinia Listeri* et var. *hybrida*, *Unicardium cardioides*, *Gryphæa arcuata*.
44	Friable shale - -	0 7	*Eucyclus elegans*, *Lima pectinoides*.
45	Friable shale and oyster-bed.	0 4	
46	Friable shale and oyster-bed.	0 8	*Dentalium etalense*, *L. gigantea* *Cardinia Listeri*.
47	Friable shale and oyster-bed.	0 6	

Middle Bucklandi-beds, 93 ft. 6½ in.

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
48	Friable shale with nodules and oyster-bed.	0 8	*Am. bisulcatus, Am. Charmassei, Eucyclus elegans, Pleurotomaria similis, P. concava, Turbo solarium, T. Philemon, Pitonillus, Cryptænia, Turritella Dunkeri, Acteonina fragilis, Dentalium etalense, Myoconcha, Monotis inæquivalvis, Lucina, Leda, Macrodon naviculus, Unicardium, Cardinia Listeri, Modiola hillanoides, M. bifasciata, Cardita, Protocardium, Lima gigantea, L. pectinoides, Pecten textorius, Gryphæa arcuata, Rhynchonella plicatissima* (var.), *Ditrypa antiquata, Pentacrinus, Montlivaltia Guettardi, M. Haimei.*
49	Friable shale and oyster-bed.	0 4	*C. Listeri, Lima pectinoides, Pecten textorius, Pentacrinus.*
50	Oyster bank - -	0 1	*L. pectinoides, Pecten textorius, Pentacrinus, Cryptænia solarioides.*
51	Stiff blue shale - -	0 9	
52	Line of blue limestone nodules.	0 1½	
53	Stiff blue shale with flat blue limestone nodules.	7 0	*Cardinia concinna.*
54	Friable shale with oyster-bed.	0 1½	*Pecten textorius, Montlivaltia Guettardi.*
55	Stiff blue shale - -	5 0	*Am. Birchii.*
56	Oyster-band - -	0 1	
57	Friable shale and depressed limestone nodules.	0 2	*G. arcuata, Cardinia Listeri, Unicardium, Modiola hillanoides, Pecten textorius, Rhynchonella plicatissima* (var.), *Am. Charmassei.*
58	Stiff blue shales - -	17 0	*Nautilus striatus, Pleuromya crassa, Pentacrinus tuberculatus,* Drift wood.
59	Thin calcareous sandstone and stiff blue shales.	9 0	
60	Oyster band 1 inch, shale 3 inches, calcareous sandstone ½ inch.	0 4½	
61	Stiff blue shale - -	14 0	
62	Friable shale with indurated top.	3 2	
63	Earthy limestone in nodules.	0 2	
64	Friable shale - -	0 11½	*Rissoa nana, Turbo solarium, T. Philemon, Discohelix semistriatus, D. Oppeli, Dentalium etalense, D. limatulum, Macrodon naviculus, M. pullus, Leda galathea, L. texturata, Nucula navis, Astarte obsoleta, Tancredia ovata, Monotis papyria.*
65	Lumpy limestone -	0 3	*Am. bisulcatus.*
66	Friable shale - -	0 1	
67	Soft shale - -	0 2	
68	Nodular limestone -	0 2	*Am. Bucklandi, Gryphæa arcuata.*
69	Shale - - -	0 4	
70	Gryphite limestone -	0 3	*Am. Bucklandi, Cryptænia, G. arcuata.*

Lower Bucklandi Beds, 19 ft. 0 in.

No.	Petrology.	Thickness. Ft.	In.	Organic Remains.
71	Soft shale - -	0	6	
72	Limestone - -	0	2½	*Am. Bucklandi.*
73	Shale - - -	0	6	
74	Gryphite limestone -	0	7	
75	Shale - - -	0	2	
76	Limestone - -	1	0	
77	Shale - - -	0	2	
78	Limestone - -	0	3	
79	Soft shale - -	0	1	
80	Limestone mixed with shale.	0	3½	
81	Soft shale - -	0	1	
82	Lumpy limestone -	0	8	
83	Friable shale with oysters	0	6	
84	Nodular limestone -	0	3	
85	Soft shale - -	0	5	
86	Limestone mixed with shale.	0	8	*Am. Conybeari.*
87	Soft shale - -	0	4	
88	Friable shale and stone -	0	8	*Pleurotomaria similis, Eucyclus elegans, Lima gigantea, L. pectinoides, Myoconcha, Lucina, Hippopodium, G. arcuata.*
89	Soft shale - -	0	9	*Plicatula liasina, Galeolaria socialis, Cidaris, Pentacrinus, Am. bisulcatus.*
90	Friable shale and limestone.	0	3	
91	Soft shale - -	1	1	
92	Friable shale with stony portions.	0	2	
93	Soft shale - -	0	2	
94	Limestone - -	0	4	
95	Friable shale with limestone.	0	4	
96	Soft shale - . -	0	9	
97	Limestone 1½ in., lumpy limestone 2 in.	0	3½	*Nautilus striatus, Astarte obsoleta, Leda galathea, Pinna Hartmanni.*
98	Soft shale - -	1	6	
99	Soft and friable shales -	0	5	
100	Shell-limestone, friable shales.	0	6	*Am. Bucklandi, Am. Conybeari, Pleurotomaria similis, Eucyclus elegans, Cryptænia solarioides, Astarte obsoleta, Ditrypa globiceps, Galeolaria socialis.*
101	Line of limestone nodules			
	Total of the *Bucklandi*-series.	179	4½	

From these sections it will be seen that the *Bucklandi*-beds of Yorkshire are very different in their petrology from those of the South of England; for while the latter consist of thick-bedded blue hydraulic limestone interstratified with clays, the Yorkshire beds are composed mainly of shale with only thin earthy shelly limestones.

Inland, where the ground is free from Drift, this is the most easily recognised of all the Lower Lias zones from the numerous fragments of shelly limestone which are scattered over the surface;

particularly is this the case in South Yorkshire, where the common fossils such as *Gryphæa* (*Ostrea*) *arcuata*, *Lima gigantea*, and *Cardinia Listeri* are so plentiful as to form thick beds of gravel, almost wholly composed of these shells, which have in many cases been transported from their original position *in situ*.

Fossils from the Zone of Am. Bucklandi.

PLANTÆ.

Equisetites sp.

CŒLENTERATA.

Montlivaltia Guettardi, *Blainville*.
Montlivaltia Haimei, *Chap. & Dew.*

ECHINODERMATA.

Extracrinus subangularis, *Miller*.
Pentacrinus basaltiformis, *Miller*.
Pentacrinus psilonoti, *Quenst.*
—— tuberculatus, *Miller*.

ANNELIDA.

Ditrupa capitata, *Phil.*
—— cylindracea, *Terquem*.
—— quinquesulcata, *Münster*.
Galeolaria socialis, *Goldf.*
Serpula deplexa, *Bean.*
—— limax, *Goldf.*
—— lituiformis, *Münster*.

CRUSTACEA.

Bairdia dispersa, *Blake*.
—— elongata, *Blake*.
—— lacryma, *Blake*.
—— liassica, *Brodie*.
—— redcarensis, *Blake*.
Cythere arcæformis, *Blake*.
—— translucens, *Blake*.
—— triangulata, *Blake*.
Cytherella paupercula, *Blake*.
Polycope cerasia, *Blake*.

BRACHIOPODA.

Discina Holdeni, *Tate*.
Rhynchonella calcicosta, *Quenst.*
Spiriferina Walcotti, *Sow.*
—— —— var. lata, *Martin*.

LAMELLIBRANCHIATA.

Avicula inæquivalvis, *Sow.*
—— papyria, *Quenst.*
Gervillia Hagenowii, *Dunker*.
Inoceramus pinnæformis, *Dunker*.
Lima gigantea, *Sow.*
—— hettangiensis, *Terquem*.
—— pectinoides, *Sow.*
—— succincta, *Schlot.*
Limea blakeana, *Tate*.
Gryphæa (Ostrea) arcuata, *Lam.*
Ostrea Goldfussi, *Bronn.*
—— semiplicata, *Münster*.
—— ungula, *Münster*.
Pecten calvus, *Goldf.*
—— lohbergensis, *Emerson*.
—— lunularis, *Röm.*
—— punctatissimus, *Quenst.*
—— textorius, *Schlot.*
—— Thiollieri, *Martin*.
Perna infraliassica, *Quenst.*
Pinna Hartmanni, *Ziet.*
Plicatula liasina, *Terquem*.
Astarte cingulata, *Terquem*.
—— obsoleta, *Dunker*.
Cardinia concinna, *Sow.*
—— crassiuscula, *Sow.*
—— Listeri, *Sow.*
—— —— var. hybrida, *Sow.*
Cardita Heberti, *Terquem*.
Cardium philippianum, *Dunker*.
Goniomya heteropleura, *Ag.*
Gresslya galathea, *Ag.*
Hippopodium ponderosum, *Sow.*
Leda galathea, *d'Orb.*
—— Renevieri, *Oppel*.
—— subovalis, *Goldf.*
—— texturata, *Terquem*.
Lucina cardioides, *Tate*.
—— limbata, *Terquem*.
Macrodon hettangiensis, *Terquem*.
—— naviculus, *Terquem*.
—— pullus, *Terquem*.
Modiola bifasciata, *Tate*.
—— hillanoides, *Chap. & Dew.*
—— lævis, *Sow.*
Myoconcha psilonoti, *Quenst.*
Nucula navis, *Piette*.
Pholadomya Fraasii, *Oppel*.
—— glabra, *Ag.*
—— ventricosa, *Ag.*
Pleuromya crassa, *Ag.*
—— Dunkeri, *Terquem*.
—— liasina, *Schübler*.
Tancredia apicistria, *Rolle*.
—— ovata, *Chap. & Dew.*
Unicardium cardioides, *Phil.*

SCAPHOPODA.

Dentalium etalense, *Terquem*.
Dentalium limatulum, *Tate*.

GASTEROPODA.

Actæonina fragilis, *Dunker*.
—— sinemuriensis, *Martin*.
Cerithium gratum, *Terquem*.
—— semele, *d'Orb*.
Chemnitzia Berthaudi, *Dum*.
—— Collenoti, *Terquem*.
—— unicingulata, *Terquem*.
Cryptænia rotellæformis, *Dunker*.
—— solarioides, *Sow*.
Discohelix Oppeli, *Martin*.
—— striatus, *Piette*.
Eucyclus Chapuisi, *Terquem*.
—— elegans, *Münster*.
—— selectus, *Chap. & Dew*.
Natica purpuroidea, *Tate*.
Phasianella morencyana, *Piette*.
Pitonillus sordidus, *Tate*.
Pleurotomaria anglica, *Sow*. (similis, *Auct*.).
—— basilica, *Chap. & Dew*.
—— concava, *Martin*.
—— Hennocqui, *Terquem*.
—— tectaria, *Tate*.
Rissoa nana, *Martin*.
Trochus redcarensis, *Tate*.
Turbo Philemon, *d'Orb*.
—— reticulatus, *Moore*.
—— solarium, *Piette*.
—— Wilsoni, *Tate*.
Turritella deshayesea, *Terquem*.
—— Dunkeri, *Terquem*.
—— regularis?, *Terquem*.
—— Zenkeni, *Dunker*.

CEPHALOPODA.

Ammonites Birchii, *Sow*.
—— bisulcatus, *Brug*.
—— Brooki, *Sow*.
—— Bucklandi, *Sow*.
—— Charmassei, *d'Orb*.
—— Conybeari, *Sow*.
—— finitimus, *Blake*.
—— Greenoughi?, *Sow*.
—— lacunatus?, *Buckm*.
—— longipontinus?, *Oppel*.
—— niger, *Blake*.
—— obesulus, *Blake*.
—— Pauli, *Dum*.
Ammonites Pellati, *Dum*.
—— rotiformis?, *Sow*.
—— sauzeanus, *d'Orb*.
—— scipionianus, *d'Orb*.
—— semicostatus, *Y. & B*.
—— sinemuriensis, *d'Orb*.
—— subplanicosta, *Oppel*.
—— Turneri, *Sow*.
Belemnites acutus, *Miller*.
—— calcar, *Phil*.
—— infundibulum, *Phil*.
—— penicillatus, *Sow*.
Nautilus striatus, *Sow*.

PISCES.

Acrodus nobilis, *Ag*.
Hybodus reticulatus, *Ag*.

REPTILIA.

Ichthyosaurus, sp.

ZONE OF AMMONITES OXYNOTUS.

Synonyms and Foreign Equivalents:—"Turnerithone," Quenstedt, Flözgeb, p. 540, 1843; "Oxynotenschichte und Raricostatenschicht," Fraas, Württemb. naturw. Jahr., p. 206, 1846; "Sable d'Aubange," Dewalque et Chapuis, Luxembourg, p. 12, 1853; "Die Schichten des *Am. obtusus*, *Am. oxynotus*, und *Am. raricostatus*," Oppel, Juraformation, pp. 50, 54, 56, 1856; "Oxynotenlager, Lias β" Quenstedt, Der Jura, p. 92, 1858; "Zone of *Am. obtusus*, *Am. oxynotus*, and *Am. raricostatus*," Wright, Quart. Journ. Geol. Soc., vol. xvi., pp. 404–411, 1860; "Calcaire marneux bleuâtre à *Am. oxynotus*, *Am. stellaris*, *Am. Birchii*, &c.," Martin, Pal. stratigr. de l'Infra-lias, 1860; "Die Schichten des *Am. ziphus*," Brauns, Der untere Jura, 1871; "Zone of *Arietites obtusus*, *Amaltheus oxynotus*, and *Arietites raricostatus*," Wright, Lias Ammonites, pp. 49-60, 1879.

This zone is divided by some geologists into three horizons, the zone of *Am. obtusus*, of *Am. oxynotus*, and of *Am. raricostatus*; but in Yorkshire, as Messrs. Tate and Blake have pointed out, there is not sufficient palæontological distinction for this separation.

It consists of a general mass of argillaceous strata; which, except at Robin Hood's Bay, it is difficult to divide up into beds, or to separate from the lower part of the overlying zone which has a similar character.

The best exposure of these beds is that in Robin Hood's Bay, where they form the larger part of the reefs that are exposed at low-water. Commencing opposite the village these beds sweep round in graceful curves till they are brought against the fault at Peak Steel, or pass beneath the water near that point.

The following is the detailed section given by Messrs. Tate and Blake at this place:—

Section of the Oxynotus-*beds, Robin Hood's Bay.*

Zone	No.	Petrology.	Thickness. Ft. In.	Organic Remains.
Zone of Ammonites raricostatus.*	1	Indurated sandy band, with nodules of broken fossils.	1 6 (e)	*Belemnites.*
	2	Blue shale - -	8 6	
	3	Hardened band - -	0 3	*Pecten priscus, Belemnites, Cardinia hybrida, Gryphæa obliquata.*
	4	Blue shale - -	7 0 (e)	*Homomya ventricosa.*
	5	Hardened band - -	0 3	
	6	Blue shale - -	4 0 (e)	
	7	Blue shale with variable indurated bands, in places thick, elsewhere thin.	7 0	
	8	Hard band - -	0 4	
	9	Soft clayey band in places	0 3	
	10	Hard blue shales -	2 6	
	11	Rubbly variegated hard band.	0 4	
	12	Blue breakable shales -	2 10	*Lima pectinoides.*
	13	Rubbly variegated band -	0 3	This and the next two bands run close together and make a feature in the cliff.
	14	Blue shale - -	0 10	
	15	Hard band - -	0 2	
	16	Shale - - -	1 0	*Nautilus striatus.*
	17	Hard band - -	0 3	
	18	Blue shales - -	3 7	*Pentacrinus tuberculatus.*
	19	Line of fossiliferous nodules.	0 3	*Am. raricostatus, Am. densinodus, Lima pectinoides, Pecten priscus, Monotis inæquivalvis.*
	20	Blue shales - -	1 8	*Pecten calvus, Lima pectinoides, Rhynchonella plicatissima.*
Zone of Ammonites oxynotus.*	21	Hard limestone band with erect annelid (?) tubes.†	0 8	*Am. Simpsoni, Nautilus striatus.*
		Parting of shale -	0 2–4	*Gryphæa obliquata, Homomya ventricosa.*
	22	Hard limestone band -	0 8–6	
	23	Blue shale crumbly -	1 3	*Am. gagateus, Lima pectinoides, Modiola lævis, Cardinia hybrida.*
	24	Hard rubbly stone	0 4	

* These divisions are adopted by Dr. Wright, who includes the beds 1-20 in the zone of *Am. raricostatus*; 21–26 in the *oxynotus* zone; and the lower portion 27–45 in the *obtusus* zone.

† This and the beds below down to 24 form a well-marked double band which comes up to the cliff at Mill Beck and is traceable across the Bay to the south end.

Zone of Ammonites obtusus.*

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
25	Blue crumbly shales with bands of scattered irregular doggers.	5 8	*Belemnites acutus, Pecten calvus, Protocardium oxynoti, Am. gagateus, Am. oxynotus.*
26	Marly stone in the form of doggers with *Pentacrinus*-band and cone-in-cone structure below.	0 2	*Pentacrinus tuberculatus, Actæonina fragilis, Hydrobia solidula, Lima pectinoides, Leda.*
27	Shales with many scattered sandstone doggers, shell-layer towards base.	5 10	*Am. planicosta, Lima pectinoides, Cardinia hybrida, Gryphæa obliquata.*
28	Hardened band - -	0 5	
29	Soft shale - -	1 7	
30	Whitened calcareous band	0 3	
31	Variable blue black shales with scattered doggers (flat).	14 0	*Pentacrinus tuberculatus.*
32	Thin whitened band -	0 2	
33	Shales - - -	1 4	*Am. sagittarius, Belemnites acutus.*
34	Whitened band - -	0 8–12	*Ostrea arcuata, Bel. acutus.*
35	Shales - - -	5 0	*Am. sagittarius, Pent. tuberculatus.*
36	Harder whitened band -	0 9	
37	Shale - - -	2 3	*Am. sagittarius, B. acutus, Ostrea arcuata.*
38	Thick whitened band -	1 8	
39	Blue shale, unseen in cliff, with line of crustacean nodules.	6 0 (*e*)	*Am. planicosta, Am. obtusus, Am. sagittarius, Am. stellaris, Hippopodium ponderosum.*
40	Hard brown limestone band forming a strong scar.†	0 5	
41	Hard blue shale with line of scattered doggers, 3 ft. down.	8 0 (*e*)	*Pecten priscus, Belemnites acutus, Ostrea arcuata, Pentacrinus tuberculatus.*
42	Hard calcareous rubbly stone forming a very strong continuous scar.†	1 3	
43	Blue shale with beds of oysters.	2 4	*Ostrea arcuata, Pentacrinus tuberculatus, Pecten priscus.*
44	Indurated limestone band	0 4–6	*Ostrea arcuata, Cardinia hybrida, Hippopodium ponderosum.*
45	Blue soft and smooth shale with round nodules.	3 6 (*e*)	*Am. planicosta.*
46	Indurated calcareo-argillaceous rubbly band, speckled brownish.	0 2	[Top of Bucklandi-beds, *see* page 40.]
	Total thickness -	107 10	

* These divisions are adopted by Dr. Wright, who includes the beds 1–20 in the zone of *Am. raricostatus*; 21–26 in the *oxynotus* zone; and the lower portion 27–45 in the *obtusus* zone.

† These two beds, 40 and 42, form very conspicuous scars, the lower of them coming just to the edge of the sands for some distance near the centre of the anticlinal axis.

The last four of these beds are only classed with the *oxynotus* zone from the occurrence of *Am. planicosta;* the base of this horizon is more marked petrologically by the strong scar No. 42.

The *oxynotus*-beds again come up at Redcar, where they form the small scar known as High Stone, and consist of alternations of blue marly shales and thin arenaceous limestone from which Messrs. Tate and Blake have obtained characteristic fossils, but the section is too obscure to call for much notice.

Inland, these beds, from being composed mostly of soft shales, are not well exposed, and it is only in a few places that they can be recognized with any certainty.

Fossils from the Zone of Am. oxynotus.

ECHINODERMATA.

Pentacrinus basaltiformis, *Miller*.
Pentacrinus tuberculatus, *Miller*.

ANNELIDA.

Ditrupa circinata, *Tate*.
Ditrupa quinquesulcata, *Münster*.

CRUSTACEA.

Cythere translucens, *Blake*.
Eryma lævis, *Blake*.
Glyphæa lyrica, *Blake*.
Pseudoglyphæa Etalloni?, *Oppel*.

BRACHIOPODA.

Rhynchonella calcicosta, *Quenst*.

LAMELLIBRANCHIATA.

Avicula inæquivalvis, *Sow*.
Gervillia Hagenowii, *Dunker*.
Lima gigantea, *Sow*.
—— pectinoides, *Sow*.
Gryphæa (Ostrea) arcuata, *Lam*.
—— cymbium, var. obliquata, *Sow*.
Ostrea Goldfussi, *Bronn*.
Pecten æqualis, *Quenst*.
—— calvus, *Goldf*.
—— priscus, *Schlot*.
Pinna folium, *Y. & B.*
—— Hartmanni, *Ziet*.
Arcomya vetusta, *Phil*.
Astarte obsoleta, *Dunker*.
Cardinia Listeri, var. hybrida, *Sow*.
Cardium oxynoti, *Quenst*.
Cucullæa Münsteri, *Ziet*.
Gresslya galathea, *Ag*.
Hippopodium ponderosum, *Sow*.
Leda galathea, *d'Orb*.
—— Heberti, *Martin*.
—— minor, *Simp*.
—— subovalis, *Goldf*.
Macrodon naviculus?, *Terquem*.
Modiola lævis, *Sow*.
—— scalprum, *Sow*.
Nucula navis, *Piette*.
Pholadomya ventricosa, *Ag*.
Unicardium cardioides, *Phil*.

GASTEROPODA.

Actæonina fragilis, *Dunker*.
Chemnitzia Collenoti, *Terquem*.
Hydrobia solidula, *Dunker*.
Trochus robigus, *Tate*.
Turritella Dunkeri, *Terquem*.
—— regularis, *Terquem*.

CEPHALOPODA.

Ammonites caprotinus, *d'Orb*.
—— carusensis, *d'Orb*.
—— Collenoti, *d'Orb*.
—— gagateus, *Y. & B.*
—— Greenoughi, *Sow*.
—— impendens, *Y. & B.*
—— lacunatus, *Buckm*.
—— obsoletus, *Simp*.
—— obtusus, *Sow*.
—— ophioides, *d'Orb*.
—— Oppeli, *Schlönb*.
—— oxynotus, *Quenst*.
—— planicosta, *Sow*.
Ammonites raricostatus, *Ziet*.
—— sagittarius, *Blake*.
—— semicostatus, *Y. & B.*
—— Simpsoni, *Bean*.
—— spiratissimus, *Quenst*.
—— stellaris, *Sow*.
Belemnites acutus, *Miller*.
—— calcar, *Phil*.
—— dens, *Simp*.
—— infundibulum, *Phil*.
—— penicillatus, *Sow*.
Nautilus intermedius, *Sow*.

ZONE OF AMMONITES JAMESONI.

Synonyms and Foreign Equivalents:—"Blue Marl" (part), W. Smith, Memoir to the Map, p. 47, 1815; "Die Belemnitenschichte" (part), Römer, Verst. Oolit., p. 4, 1836; "Numismalismergel oder Belemnitenschiefer," Quenstedt, Flözgeb., p. 164, 1843; "Die Schichten des *Ammonites Jamesoni*," Oppel, Juraformation, p. 118, 1856; "Jamesoni-bed," Wright, Quart. Journ. Geol. Soc., vol. xiv., p. 25, 1858; "Rostige kalkmergel,

Lias γ," Quenstedt, Der Jura, p. 115, 1858; "The Zone of *Am. Jamesoni*," Wright, Proc. Cottesw. Nat. Club, 1869; "Die Schichten des *Am. Jamesoni* und *Am. centaurus*," Brauns, Der untere Jura, pp. 100, 111, 1871; "Zone of *Ægoceras Jamesoni*," Wright, Lias Ammonites, p. 69, 1879.

With this zone, in the opinion of most palæontologists, we enter the Middle Lias, although, for reasons stated previously, this is not a convenient line to adopt in the survey of a district, particularly after leaving the coast sections. Palæontologically, however, a considerable change occurs between the fauna of this zone and that below, and it is here that the greatest break in the succession of life takes place.

Messrs. Tate and Blake divide this zone into two portions, the upper part being the zone of *Am. Jamesoni* proper, while the lower portion constitutes their subzone of *Am. armatus*. On the Continent and in some parts of England the highest beds have been separated into a distinct horizon, under the name of the zone of *Am. ibex*.

Among Continental authors this zone has also received the names of "Numismalis marls" and "Belemnite marls," from the abundance of *Waldheimia numismalis* and *Belemnites* of several species in it. The former of these shells has not been found in Yorkshire, but the latter appellation is equally applicable to the beds of this district.

The zone of *Am. Jamesoni* is easily distinguished from the rest of the Lower Lias by its more micaceous character, and by its containing lines of small ironstone nodules or "doggers," which in the lower part usually consist of iron pyrites often in distinct crystals. The abundance of pyrites in these beds is a very characteristic feature, some of the ammonites being entirely composed of it. The *Jamesoni*-beds are well seen on both sides of Robin Hood's Bay; but it is only on the north side that they can be measured and easily examined.

Messrs. Tate and Blake have measured these beds where they crop out just north of the village, and give the following details:—

Section of the Jamesoni-*beds, Robin Hood's Bay.*

	No.	Petrology.	Thickness.	Organic Remains.
			Ft. In.	
		Shale - - -	4 5	*Am. capricornus.*
		Dogger - - -	0 5–10	
		Base of *capricornus* beds.		
These beds are included in the capricornus zone in the section given on page 56.*	1	Light hard crumbly shale	5 0	
	2	Dogger - - -	0 6	
	3	Shale - - -	10 0	
	4	Irregular dogger -	—	
	5	Shale - - -	4 0	
	6	Brown sandy layer -	0 3	
	7	Shale - - -	5 3	

* The sections of the *Jamesoni* and the *capricornus*-beds at Robin Hood's Bay, as given by Messrs. Tate & Blake, overlap. Compare the Yorkshire Lias, pp. 79 and 91.

No.	Petrology.	Thickness. Ft.	In.	Organic Remains.
8	Variable dogger - -	2	6	
9	Shale with indurated bands and nodules.	13	6	*Am. Henleyi,* Am. fimbriatus, Ophioderma Gaveyi.*
10	Scattered dogger band -	0	0–12	
11	Shale - - -	2	9	
12	Dogger - - -	0	3	
13	Hard crumbly shale -	13	0	*Belemnites elegans.*
14	Dogger - - -	0	6	
15	Bluer shale - -	2	0	
16	Irregular dogger -	—		
17	Bluer shale - -	7	0	*Am. brevispina, Gryphæa obliquata, Modiola scalprum, Pleuromya ovata.*
18	Well marked dogger -	0	3	*Belemnites araris, B. elegans, Monotis inæquivalvis.*
19	Hard grey indurated shale with more indurated band in the middle.	11	6	*Lima acuticosta, Pecten æquivalvis, Pinna folium,* Wood.
20	Dogger - - -	0	3	
21	Blue shale - -	2	4	
22	Dogger - - -	0	4	
23	Blue shale - -	5	0	*Gryphæa obliquata, Am. brevispina.*
24	Dogger - - -	0	3	
25	Shale - - -	1	10	*Pecten priscus, Chemnitzia Blainvillei.*
26	Regular dogger - -	0	6	
27	Shale - - -	3	10	*Gresslya striata, Leda galathea, Plicatula spinosa, Pinna folium, Belemnites araris, B. virgatus.*
28	Irregular dogger - -	0	6	
29	Shale - - -	3	0	*Am. brevispina, Am. polymorphus, Ditrypa circinata.*
30	Dogger - - -	0	5	
31	Shale - - -	1	0	
32	Dogger - - -	0	5	*Modiola scalprum.*
33	Shale - - -	14	8	*Am. lynx., Am. polymorphus, Pholadomya decorata* (vertical), *Pecten priscus, Pleuromya ovata.*
34	Dogger - - -	0	6	*Pholadomya decorata* (vertical).
35	Shale - - -	5	4	*Pholadomya decorata.*
36	Irregular dogger -	—		
37	Shale - - -	4	3	*Pecten priscus, Lima Hermanni.*
38	Irregular dogger - -	—		
39	Shale - - -	5	3	*Unicardium cardioides.*
40	Irregular dogger - -	—		
41	Shale - - -	3	0	*Rhynchonella plicatissima, Arcomya elongata, Ditrypa circinata, Pinna folium.*
42	Irregular dogger - -	—		
43	Shale - - -	4	0	*Pecten priscus, Gryphæa obliquata, Gresslya ovata,* Crustacea.
44	Strong dogger - -	0	8	*Pinna folium.*
	Base of *Jamiesoni*-beds proper.			

* This is given as *A. striatus* in the section of the *capricornus*-beds.

No.	Petrology.	Thickness.		Organic Remains.
		Ft.	In.	
45	Blue shale	10	0	*Pinna folium, Cucullæa Münsteri, Limea acuticosta, Arcomya vetusta, Glyphæa Terquemi, Lima Hermanni.*
46	Ironstone dogger	0	8	
47	Blue shale with pyritous nests, full of fossils about 5 feet down. (Is at the base of the cliff, making the point to the south, of the north cheek of the bay.)	15	8	*Lima Hermanni, Monotis inæquivalvis, Gryphæa obliquata, Waldheimia sarthacensis, Pecten priscus, Pinna folium, Spiriferina Walcotti* var., *Pleurotomaria procera, Rhynchonella plicatissima, Protocardium oxynoti, Cucullæa Münsteri, Trigonia,* sp., *Nucula cordata, Am. armatus, Am. Taylori, Belemnites, Gresslya ovata, G. striata.*
48	Dogger	0	4	
49	Blue shale	12	0	
50	Band of rotted clay	0	2	
51	Ironstone dogger well marked in cliff.	0	3	*Inoceramus ventricosus, Pecten calvus, Chemnitzia Blainvillei.*
52	Blue shale	5	0	
53	Strong ironstone dogger	0	4	*Gryphæa obliquata.*
54	Blue shale, with doggers and nests of fossils scattered.	24	0	*Ditrypa circinata, Am. armatus, Pecten priscus, Belemnites.*
—	Thin line of broken fossils	0	1	*Belemnites, Pecten priscus, Cerithium, Rhynchonella variabilis, Ammonites* (small).
55	Blue shale full of Belemnites and Gryphæas.	5	6	*Am. armatus, Belemnites, Rhynchonella tetrahedra, Am. planicosta, Gryphæa obliquata, Anomia numismalis, Leda subovalis, Limea acuticosta, Pecten priscus, Cucullæa Münsteri, Pinna folium.*
56	Ironstone dogger	0	3	
57	Blue shale	3	0	*Am. tubellus, Am. armatus.*
58	Scattered irregular doggers, and blue shale.	3	0	*Am. turdecrescens, Pecten substriatus, P. calvus, Cucullæa Münsteri.*
59	Argillaceous ironstone dogger with cone-in-cone structure at the top.	0	4	
60	Blue shale (a few inches only seen in the cliff).	8	6(*e*)	*Limea acuticosta, Pentacrinus, Am. Macdonelli, Am. tubellus, Belemnites elegans.*
	Base of the zone of *A. armatus.*			
	Total thickness	225	8	

North of this point the *Jamesoni*-beds are not seen till they are brought up by the anticlinals at Rockcliff and Huntcliff; at both of which places they occupy the shore and the lower part of the cliff for some distance; but there is no complete section that can be measured, nor is it easy to fix their upper limit very accurately. Besides these the only remaining outcrop on the coast is that on the scars to the north of Redcar, where beds belonging to this

zone are exposed at the north edge of High Stone, and along the southern portion of Coatham or West Scar, but these sections are very obscure and only visible on favourable opportunities.

The junction of this zone with that of Capricornus is not very definite; and, within a few feet, it is not possible to say exactly where to draw the line between them; for this reason it would appear that, at Robin Hood's Bay, Messrs. Tate and Blake have included the upper 25 feet in the sections of both zones. The thickness of these beds may therefore be stated roughly at from 200 to 225 feet.

It is very possible that these beds which contain *Am. striatus* may to a certain extent represent the zone of *Am. ibex* of the South of England, but in the absence of more definite palæontological evidence one is not justified in so considering them.*

Fossils from the Zone of Am. Jamesoni.

ECHINODERMATA.

Cidaris Edwardsii ?, *Wright.*
Hemipedina, sp.
Pseudodiadema Slateri, *Blake.*
Ophioderma Gaveyi, *Wright.*
Pentacrinus Milleri ?, *Austin.*
—— scalaris, *Goldf.*

ANNELIDA.

Ditrupa capitata, *Phil.*
—— circinata, *Tate.*
—— quinquesulcata, *Münster.*
Serpula deplexa, *Bean.*
—— plicatilis, *Goldf.*

CRUSTACEA.

Glyphæa Terquemi, *Oppel.*
Pollicipes alatus ?, *Tate*
Pseudoglyphæa hamifera, *Blake.*

BRACHIOPODA.

Lingula sacculus, *Chap. & Dew.*
Rhynchonella calcicosta, *Quenst.*
—— furcillata, *Theodori.*
—— oxynoti, *Quenst.*
—— rimosa, *Von Buch.*
—— subconcinna, *Dav.*
Rhynchonella tetrahedra, *Sow.*
Spiriferina oxyptera, *Buvig.*
—— Walcotti, var. lata, *Martin.*
Thecidium belemniticum, *Tate.*
Waldheimia perforata, *Piette.*

LAMELLIBRANCHIATA.

Anomia numismalis, *Quenst.*
Avicula inæquivalvis, *Sow.*
Gervillia ærosa, *Simp.*
Inoceramus ventricosus, *Sow.*
Lima eucharis, *d'Orb.*
—— Hermanni, *Voltz.*
Limea acuticosta, *Münster.*
—— juliana, *Dum.*
Gryphæa cymbium, var. obliquata, *Sow.*
Ostrea Goldfussi, *Bronn.*
—— sportella ?, *Dum.*
Pecten æquivalvis, *Sow.*
—— calvus, *Goldf.*
—— lunularis, *Röm.*
—— priscus, *Schlot.*
—— substriatus, *Röm.*
Pinna folium, *Y. & B.*
Plicatula spinosa, *Sow.*
Arcomya elongata, *Röm.*
—— vetusta, *Phil.*
Astarte striato-sulcata, *Röm.*
Cardinia attenuata, *Stutch.*

* Messrs. Tate and Blake, pp. 78, 79, appear to have confused *Am. striatus* with *Am. Henleyi*, although they notice the distinction in the second part of their work.

LAMELLIBRANCHIATA—*cont.*

Cardita multicostata, *Phil.*
Cardium oxynoti, *Quenst.*
—— truncatum, *Sow.*
Cucullæa Münsteri ?, *Ziet.*
Cypricardia cucullata, *Münster*
Goniomya hybrida, *Münster.*
Gresslya punctata, *Simp.*
—— striata, *Ag.*
Hippopodium ponderosum, *Sow.*
Leda complanata, *Goldf.*
—— galathea, *d'Orb.*
—— minor, *Simp.*
—— subovalis, *Goldf.*
Leda Zieteni, *Brauns.*
Macrodon intermedius, *Simp.*
—— pulchellus, *Tate.*
Modiola numismalis, *Oppel.*
—— scalprum, *Sow.*
Nucula cordata, *Goldf.*
Pholadomya ambigua, *Sow.*
—— decorata, *Ziet.*
Pleuromya costata, *Y. & B.*
—— ovata, *Röm.*
Saxicava arenicola ?, *Terquem.*
Trigonia modesta ?, *Tate.*
Unicardium cardioides, *Phil.*

GASTEROPODA.

Actæonina marginata, *Simp.*
Cerithium Slatteri, *Tate.*
Chemnitzia Berthaudi, *Dum.*
—— Blainvillei, *Münster.*
—— carusensis, *d'Orb.*
—— foveolata, *Tate.*
—— Youngi, *Simp.*
Eucyclus gaudryanus, *d'Orb.*
—— imbricatus, *Sow.*
Hydrobia solidula ?, *Dunker.*
Pleurotomaria foveolata, var. pinguis ?, *Desl.*
Trochus thetis, *Münster.*
Turritella Dunkeri, *Terquem.*

CEPHALOPODA.

Ammonites accipitris, *Buckm.*
—— aculeatus, *Simp.*
—— acuticostatus, *Wright.*
—— antiquus, *Wright.*
—— armatus, *Sow.*
—— brevispina, *Sow.*
—— fimbriatus, *Sow.*
—— Heberti ?, *Oppel.*
—— Jamesoni, *Sow.*
—— Loscombi, *Sow.*
—— lynx, *d'Orb.*
—— nodotianus, *d'Orb.*
—— pettos, *Quenst.*
—— socialis, *Simp.*
—— striatus, *Rein.*
Ammonites tardecrescens, *Haue.*
—— Taylori, *Sow.*
—— trivialis, *Simp.*
—— tubellus, *Simp.*
—— Valdani ?, *d'Orb.*
—— validus, *Simp.*
Belemnites apicicurvatus, *Blain.*
—— araris, *Dum.*
—— charmouthensis, *Mayer.*
—— clavatus, *Blain.*
—— elegans, *Simp.*
—— palliatus, *Dum.*
—— penicillatus, *Sow.*
—— virgatus, *Mayer.*
Nautilus araris, *Dum.*

REPTILIA.

Plesiosaurus, sp.

ZONE OF AMMONITES CAPRICORNUS.

Synonyms and Foreign Equivalents:—" Der mittlere schwarze Jura " (part), Quenstedt, Flözgeb, p. 172, 1843; " Die Schichten des *Ammonites Davöi*," Oppel, Juraformation, p. 126, 1856; " Schiste d'Ethe," Dewalque, Soc. Géol. de Fr., 1854, and Lias du Luxembourg, p. 55, 1857; " Davoeikalk, Lias γ," Quenstedt, Der Jura, p. 116, 1858; " *Davœi*-bed," Wright, Quart. Journ. Geol. Soc., vol. xiv., p. 25, 1858; " Zone of *Ammonites capricornus*," Wright, Oolitic Asteroidea, Pal. Soc., p. 79, 1863; " Zone de la *Belemnites clavatus* " (part), Dumortier, Dep. Jurassique," p. 16, 1869; " Zone of *Aegoceras Henleyi*," Wright, Lias Am., p. 87, 1879.

The limits of this zone and of the next two above, namely, those of *Am. margaritatus* and *Am. spinatus* do not coincide with the most marked breaks in the petrological character of the rock.

Consequently it is necessary, in describing these zones, to take rather different subdivisions from those previously adopted by the Geological Survey, which are founded mainly on physical conditions.

Each of the two series into which we divide the Middle Lias contains a considerable thickness of beds which palæontologically belongs to the zone below; so that, in treating of this zone, we have to include the lower portion of what really belongs to the Middle Lias. For this reason we propose, in this *résumé* of what has been published on the subject, to give first of all a short sketch of these zones from the admirable account of them by Messrs. Tate and Blake, reserving for the subsequent pages a more detailed account of the Middle Lias as divided by the Survey and others. This plan has the objection of obliging us to give the same sections twice over; but, as it is generally impossible to compare the measured sections of different authors, we think it preferable to give the cliff sections as measured by the Survey separately, rather than attempt to correlate one with the other.

The zone of *Am. capricornus* is fairly well defined by the range of the characteristic ammonite; but its upper limit does not, as we have observed, coincide with the principal change in the petrological character of the rock; consequently there is a considerable difference between the lower beds of this zone, and the upper portion, which we include with the "Sandy Series" of the Middle Lias. It consists of a grey micaceous shale, which is dark coloured in the lower part, but becomes lighter and more sandy above passing gradually into the overlying sandstones. It is characterized by lines of argillaceous and ferruginous nodules which are often septariated and contain zinc blende, the prevailing ammonite being frequently entirely composed of this mineral. Some of these lines of nodules are very continuous and can be traced as far as the shales in which they occur are visible. Mr. Barrow states that two in particular are very persistent and may be observed in the cliffs at Robin Hood's Bay, Staithes, and Saltburn; the upper of these contains *Am. fimbriatus* while the lower is a thin seam of white speckled clay-ironstone, with a layer of small *Pectens* and *Belemnites* at the base. Others, no doubt, are generally persistent, but have no sufficiently marked peculiarities by which they can be traced. Some of these nodules are nearly perfect spheres, and when they fall out on to the shore their globular form has given rise to the popular idea that they were cannon balls. An immense accumulation of such blocks may be seen at the foot of the cliff on the north-west side of the Peak fault, the place from which they have fallen being inaccessible.*

On the north side of Robin Hood's Bay these beds, which succeed those of the *Am. Jamesoni* zone, crop out on the shore nearly as far as Castle Chamber, where Messrs. Tate and Blake give the following section of them :—

* Explanation of Quarter-Sheet 95 N.W. (Geol. Survey), p. 7.

Section of the Capricornus-*beds, Robin Hood's Bay.*

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
	Dark speckled shale (base of *margaritatus*-beds).	0 5	
1	Series of thin oyster-bands with ripple-marked sandstone between.	4 5	*Gryphæa cymbium*, var. *depressa*.
2	Hard speckled shales -	4 8	
3	White hardened band, conspicuous at Castle Chamber.	0 6	
4	Brown speckled shales -	8 6	Wood.
5	Sandy laminated rock, oysters at the base, 10–12 in.	0 10	*Gryphæa cymbium*, var. *depressa*.
6	Brown speckly shales -	1 4	
7	Line of ironstone doggers	0 4	*Am. capricornus*.
8	Brown speckly shales -	7 4	*Am. capricornus*.
9	Sandy variable bands, occasional patches of oysters.	0 10	
10	Brown speckly shales with large doggers irregularly scattered.	3 6	*Gryphæa cymbium*, var. *depressa*.
11	Thin laminated shale -	1 8	
12	Oyster bed (the lowest) -	0 5	*Gryphæa cymbium*, var. *depressa*.
13	Hard whitish slippery shales.	4 9	
	Irregular white doggers -	—	*Am. capricornus*, *Pholadomya Beyrichii*.
14	Similar shales - -	4 6	
	Irregular white doggers.	—	
15	Similar shale -	5 0	
	Irregular bands of white doggers.	—	
16	Similar shales - -	11 0	*Am. capricornus*.
17	Small round nodules -	0 2	
18	Darker shales, still hard -	2 10	
19	Strong ironstone dogger -	0 8	
20	Bluish hard sandy shale -	15 6	
21	Ironstone dogger, 6–8 in.	0 6	
22	Similar shale - -	8 4	
23	Ironstone dogger -	0 4–6	*Am. capricornus*, *Modiola scalprum*.
24	Similar shale - -	5 0	
25	Thin lenticular dogger -	0 3	*Monotis inæquivalvis*.
26	Similar shale - -	4 5	*Am. capricornus*, *Inoceramus ventricosus*, *Modiola numismalis*.
27	Ironstone dogger, 5–10 in.	0 5	
28*	Whitish crumbly hard shale.	5 0	
29	Dogger - - -	0 6	
30	Shale - - -	11 0	
	Irregular dogger.	—	
31	Shale - - -	4 0	*Am. fimbriatus*.
32	Brown hard band of shale	0 3	
33	Shale - - -	5 3	
	(Base of *capricornus* beds.)		
		124 0	

* This and the beds below are included in the zone of *Am. Jamesoni* (page 50), showing that the division between the two zones is purely arbitrary.

At the North Cheek the *capricornus*-beds sink beneath the level of the water, and do not appear again till we get to Staithes, where the upper part of the series is exposed at Colburn or Staithes Nab, and is as follows :—

Section of the Capricornus-*beds* (*upper part*), *Staithes.*

No.	Petrology.	Thickness. Ft. In.	Organic Remains.
	Assumed base of the *margaritatus*-beds.		
1	Compact sandy marl, layer of oysters at the top.	2 0	
2	Compact sandy marl -	8 2	
3	Grey friable sandy marls	5 5	Starfish beds.
4	Grey soft sandstone in block, oysters on the under surface.	3 9	
5	Sandy shale - -	2 3	
	Indurated sandstone -	0 0½	
6	Grey marl - -	2 9	
7	Hard sandstone, slightly calcareous.	0 4	*Limea acuticosta.*
8	Bluish marl - -	5 2	Scattered oysters (*G. cymbium*), wood. Base of cliff washed at high tides.
9	Grey argillaceous sandstone, striped with thin bands of whitish sandstone in the lower part.	3 9	
	Layer of oysters - -		
10	Grey sandy marls with detached nodules.	3 4	*Ammonites capricornus, Protocardium truncatum, Pecten æquivalvis, P. lunularis, Avicula inæquivalvis.*
	Dogger bands of argillaceous limestone.	to 4	
11	Grey marly shale, with thin bands of oysters.	5 8	*Pecten æquivalvis.*
12	Oyster band - -	0 4	
13	Grey marly shales, layer of oysters, and scattered doggers.	4 2	
14	Oyster band in ferro-argillaceous matrix, weathering red.	0 8	*Am. capricornus, Eucyclus undatus, Leda minor, Gervillia ærosa, Pecten substriatus, Avicula inæquivalvis, Limea acuticosta, Rhynchonella calcicosta.*
15	Grey shale - -	0 9	
16	Dogger band - -	0 4	
17	Grey marly shale with oysters.	6 4	
18	Impure calcareous rock -	0 5	
	Grey shales and doggers.		

Below this there occurs over 100 feet of shales with regular lines of doggers.

The strata here are more arenaceous than they are further north, and are remarkable for the number of the remains of starfish they contain in the upper part.

From this point the beds continue to rise in the cliff till at Boulby they attain their greatest elevation, when they once more begin to decline, so that at Hummersea only the upper beds are visible. The section here is :—

Section of the Capricornus-*beds* (*upper part*), *Hummersea.*

No.	Petrology.	Thickness. Ft.	In.	Organic Remains.
	Base of the *margaritatus*-beds.			
1	Marly sandstone, gypsum in the joints.	4	3	*Am. capricornus, Pecten æquivalvis, Gryphæa cymbium, Protocardium truncatum, Rhynchonella calcicosta, Ditrypa circinata.*
2	Sandstone, gypsum in the joints.	1	7	
3	Calciferous sandstone, ditto.	0	3	
4	Sandy marls, ditto -	2	4	*Pecten æquivalvis.*
5	Bluish-brown fine-grained argillaceous limestone in the form of lenticular nodules.	0	4	
6	Marly sandstone - -	5	9	
7	Soft sandstone with oysters at the base.	1	3	
8	Mottled sandy marls -	11	0	
9	Denser ditto - -	2	0	
10	Mottled sandy marls -	4	0	
11	Brown compact argillaceous limestone doggers.	0	4½	
12	Mottled sandy marls -	4	8	*Pleuromyæ.*
13	Blue flaggy sandstone -	1	0	
14	Sandy-bed - -	0	6	
15	Oyster-band - -	0	4	
16	Hard sandy band -	1	5	
17	Oyster bed, usually a hard ferro-argillaceous matrix, sometimes a reddish-yellow sandstone.	0	3	*Am. capricornus, Pecten æquivalvis, P. substriatus, Protocardium truncatum, Monotis inæquivalvis, Leda minor, Gryphæa cymbium, Rhynchonella calcicosta, Ditrypa quinquesulcata, Ophioderma Milleri.*
18	Sandy shale - -	0	6	
19	Oyster-band - -	0	6	*Belemnites elegans, Gryphæa cymbium, Pecten æquivalvis, P. substriatus, Monotis inæquivalvis, Rhynchonella calcicosta.*
20	Sandy shale - -	2	0	*Am. capricornus, Bel. breviformis, Gryphæa cymbium, Pholadomya ambigua, Modiola scalprum.*
21	Dark blue to brown ferro-argillaceous limestone weathering red.	0	4	*Gresslya ovata.*
22	Bluish grey sandy marl -	0	7	
23	Shell-bed - -	0	1	*Pholadomya ambigua.*
24	Bluish grey sandy marl, detached doggers.	3	0	*Belemnites elongatus, Gryphæa cymbium.*

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
25	Marly shale with occasional calciferous sandstone masses. Sandstone parting - Grey marly shale -	2 3	*Pecten æquivalvis, P. substriatus. Gresslya ovata, Rhynchonella calcicosta.*
26	Grey marly shale with three rows of blue hard argillaceous limestone doggers.	5 8	*Am. capricornus, Bel. clavatus, B. elegans, Actæonina marginata, Chemnitzia Blainvillei, Protocardium truncatum, Pecten æquivalvis. Lima Hermanni, Limea acuticosta, Monotis inæquivalvis, Gervillia ærosa, Hippopodium ponderosum, Rynchonella calcicosta.*
27	Bluish shale with roundish nodules. (Base of cliff, high-water mark.)	3 0	*Am. capricornus, Pecten æquivalvis, Rhynchonella.*
	Total thickness -	59 2½	

West of this the beds again rise, so that at Huntcliff we get a lower portion of the series exposed. Messrs. Tate and Blake consider that there is about 45 feet of strata intervening between this section and the one at Hummersea.

Section of the Capricornus-*beds* (*lower part*), *Huntcliff* (West End).

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
1	Greenish sandy beds - Blue hard shale in blocks and bands of doggers. Blue hard shale in thick blocks. Dogger band - -	30 0	*Am. hybrida, Leda graphica, Limea acuticosta, Monotis inæquivalvis. Chemnitzia Blainvillei.*
2	Blue hard shale in large blocks with bands of greenish shaly sandstone, radiated crystals of selenite in the partings.	10 0	*Am. fimbriatus, Am. capricornus, Bel. clavatus, Monotis inæquivalvis, Inoceramus ventricosus, Lima eucharis, L. Hermanni, Pecten lunularis, P. æquivalvis, Rhynchonella tetrahedra.*
3	Nodular band of argillaceous limestone.	0 5	
4	Greyish blue hard shale in thick blocks somewhat sandy.	6 4	*Am. capricornus, Belemnites clavatus, Inoceramus ventricosus.*
5	Nodular band of brown argillaceous limestone.	0 5	*Pecten lunularis.*
6	Greyish blue sandy shale	6 3	*Pecten æquivalvis.*

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
7	Double bed of argillaceous limestone in irregular broken masses.	0 10	.
8	Blue shales - - Spherical balls of pyritous and argillaceous limestone. Blue shale - - Lenticular doggers occasionally. Blue shale - -	9 0	*Am. fimbriatus*, *Am. capricornus*, *Bel. clavatus*, *B. elegans*, *Inoceramus ventricosus*, *Pholadomya Beyrichii*, *Pecten priscus*.
9	Lenticular argillaceous limestone masses, and globular doggers; cone-in-cone structure atop in places.	0 10	*Belemnites clavatus*, *Inoceramus ventricosus*.
	Assumed base of the *capricornus*-beds.		

Below this are alternations of shales and doggers, having a thickness of about 54 feet containing towards the base *Am. striatus*, *Am. Jamesoni*, *Bel. elegans*, *Pinna folium*, &c. Allowing a space of 45 feet between these two last sections, it would make the full thickness of the *Capricornus*-beds in this neighbourhood about 170 feet according to Messrs. Tate and Blake's estimate.*

From the foregoing sections it will be seen that the Capricornus-zone includes a considerable thickness of beds belonging to the Sandy Series of the Middle Lias as mapped by the Survey, and Mr. Barrow states that he has found the characteristic ammonite considerably higher than noted by Messrs. Tate and Blake, so that it would appear that this is a case where the upper limit of the zone is not so well defined by the disappearance of the prevailing ammonite as by the change in the general assemblage of the fossils.

Fossils from the Zone of Am. capricornus.

ECHINODERMATA.

Cidaris Edwardsii, *Wright*.
Astropecten Hastingiæ, *Forbes*.
Ophioderma carinata, *Wright*.
—— Gaveyi, *Wright*.
—— Milleri, *Phil.*
Ophiolepis Murravii, *Forbes*.
Ophiurella columba ?, *Blake*.
Plumaster ophiuroides ?, *Wright*.
Solaster Murchisoni, *Williamson*.
Tropidaster pectinatus, *Forbes*.
Uraster carinatus, *Wright*.
Pentacrinus interbrachiatus, *Blake*.
—— Milleri ?, *Austin*.

ANNELIDA.

Ditrupa circinata, *Tate*.
Ditrupa quinquesulcata, *Münster*.

* That portion of Huntcliff where the highest beds in this section crop out is inaccessible, consequently it is not possible to be very accurate in the determination of the thickness.

Crustacea.

Bairdia liassica, ***Brodie.***
Cytherella crepidula, ***Blake.***

Brachiopoda.

Rhynchonella calcicosta, ***Quenst.***
—— oxynoti, ***Quenst.***
Rhynchonella subconcinna ?, ***Dav.***
—— tetrahedra, ***Sow.***

Lamellibranchiata.

Anomia numismalis, ***Quenst.***
Avicula calva. ***Schlönb.***
—— inæquivalvis, ***Sow.***
Gervillia ærosa, ***Simp.***
Inoceramus substriatus, ***Münster.***
—— ventricosus, ***Sow.***
Lima Hermanni, ***Voltz.***
Limea acuticosta, ***Münster.***
Gryphæa cymbium, var. depressa, ***Phil.***
Pecten æquivalvis, ***Sow.***
—— calvus, ***Goldf.***
—— lunularis, ***Röm.***
—— substriatus, ***Röm.***
Plicatula spinosa, ***Sow.***
Astarte striato-sulcata, ***Röm.***
Cardium truncatum, ***Sow.***
Cucullæa Münsteri ?, ***Ziet.***
Hippopodium ponderosum, ***Sow.***
Leda galathea, ***d'Orb.***
—— graphica, ***Tate.***
—— minor, ***Simp.***
Macrodon intermedius, ***Simp.***
Modiola numismalis, ***Oppel.***
—— scalprum, ***Sow.***
—— Thiollierei, ***Dum.***
Myoconcha decorata, ***Münster.***
Pholodomya ambigua, ***Sow.***
—— Beyrichii, ***Schlönb.***
Pleuromya costata, ***Y. & B.***
—— ovata, ***Röm.***
Thracia Grotiani ?, ***Brauns.***

Gasteropoda.

Actæonina ilminsterensis, ***Moore.***
—— marginata, ***Simp.***
Chemnitzia Blainvillei, ***Münster.***
—— citharella, ***Tate.***
Eucyclus cingendus, ***Tate.***
—— imbricatus, ***Sow.***
—— undulatus, ***Phil.***
Pleurotomaria foveolata, ***Desl.***

Cephalopoda.

Ammonites Bechei, ***Sow.***
—— capricornus, ***Schlot.***
—— defossus, ***Simp.***
—— diversus ?, ***Simp.***
—— fimbriatus, ***Sow.***
Ammonites heterogenes, ***Y. & B.***
—— lineatus ?, ***Schlot.***
Belemnites apicicurvatus, ***Blain.***
—— aspergillum, ***Blake.***
—— breviformis, ***Voltz.***
—— clavatus, ***Blain.***

Reptilia.

Plesiosaurus, sp.

Lower Lias.

General Account.

As we have shown in the previous pages, the Lower Lias according to us includes six well-marked zones characterised in descending order by the following ammonites. 1. *Ammonites capricornus*, Schloth. 2. *Ammonites Jamesoni*, Sow. 3. *Ammonites oxynotus*, Quenst. 4. *Ammonites Bucklandi*, Sow. 5. *Ammonites angulatus*, Schloth. 6. *Ammonites planorbis*, Sow.

These first appear on the Coast immediately north of the Peak fault at Robin Hood's Bay, being brought up by the great anticlinal axis which has exposed nearly the whole of this series. The arched form of the strata here causes the several sub-divisions to sweep round the bay in graceful curves, till they are lost beneath the level of the water opposite the North Cheek, the headland forming the northern arm of this picturesque bay

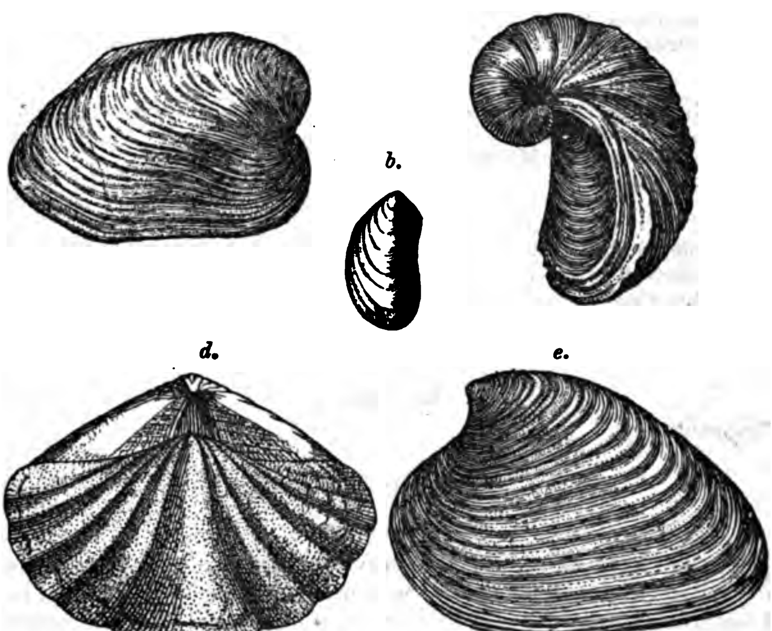
Mr. Barrow has given the following summary of the rocks seen at this place* :—

Soft shales with rows of ironstone doggers and pyritous nodules, 320 ft.	Soft shales with rows of ironstone doggers: *Am. capricornus; Gryphæa obliquata.* (Zone of *Am. capricornus.*) Soft shales with rows of pyritous nodules: *Am. Jamesoni, Gryphæa obliquata, Pinna folium.* (Zone of *Am. Jamesoni.*)
Soft shales with a succession of sandy and marly bands, 140 ft.	Shales with hard sandy bands, the upper parts covered by fucoidal markings: *Gryphæa arcuata* in scattered groups of 5 or 6; *Ammonites* abundant. (Zone of *Am. oxynotus.*) Shales with marly calcareous bands, generally very shelly: *Gryphæa arcuata; Hippopodium ponderosum* occurring in bands; *Ammonites semicostatus.* (Zone of *Am. Bucklandi.*)

FIG. 1.

Lower Lias Fossils.

a. c.



a, Hippopodium ponderosum, *Sow.* (Original) ½; *b*, Modiola minima, *Sow.* (Original) 1½; *c*, Gryphæa (Ostrea) arcuata, *Lam.* (Original) ⅔; *d*, Spiriferina Walcotti, *Sow.* (after Davidson); *e*, Cardinia Listeri, *Sow.* (after Goldfuss).

* The stratigraphical details in this and succeeding chapters are taken from previous memoirs of the Geological Survey treating of the district. Of this area the central moorland between the Murk Esk and Bilsdale was surveyed by Mr. C. Reid; while the whole of the ground north of this, including all north of a line running east and west through Peak as well as the moors west of Bilsdale, and the low ground east of Northallerton and Thirsk, was surveyed by Mr. G. Barrow. As the information derived from these sources has had to be frequently re-arranged and altered to suit the present description we have not made a separate acknowledgement in each case.

North of this point the Lower Lias does not reappear till we reach Staithes; where on the north side of Colburn Nab the upper portion again rises above the level of the sea, and continues to occupy the lower part of the cliff and foreshore all the way to Saltburn.

At this place the higher beds begin to turn inland, and are almost completely hidden by Boulder-Clay for a considerable distance*; the first sections in this portion of the series being in Yearby Wood and just above Wilton, where the so-called "Sandstone Quarry" is in shales apparently belonging to this horizon.

The lower beds after being exposed on the shore opposite Redcar are again met with in the boring at Coatham and in the Eston Gypsum Pit,† but there are no natural sections in these beds till we get beyond Eston Hill. Here, in the stream between Ormesby and Marton, beds with *Gryphæa arcuata* are exposed; and in the quarries for whinstone, near Nunthorpe, shales with calcareous nodules are seen, which evidently belong to the *Bucklandi*-zone, although the beds are so altered by contact with the dyke that it is not easy to determine the species of the fossils. Messrs. Tate and Blake however record the following, chiefly in the form of casts:—*Ammonites semicostatus*, *Pecten Thiolleri*, *Cardinia hybrida*, *Lucina limbata*, *Hippopodium ponderosum*, *Unicardium cardioides*, *Ostrea arcuata*, and *Eryon* sp.

In the stream at Ayton shales with a hard band are exposed, from which *Ammonites oxynotus*, *Am. gayateus*, *Cardium oxynoti*, and *Lima pectinoides* have been obtained, and which are therefore rather higher in the series.

At Osborne Rush Plantation on the south side of Eston Hill a deep sinking and boring has been made which went through the greater part of the Lower Lias. The beds comprised dark shales and stone beds to a depth of 426 feet.‡

On the south side of the Guisbrough valley the higher beds are seen near Hutton Hall and in the steep railway bank near Pinchinthorpe. There are several sections of these beds also in the scars at the foot of Roseberry Topping and along the line of the Whinstone Dyke to the south, where nearly the whole of this portion of the Lias is exposed.

Along the valley of the Leven between Easby and Kildale the stream affords numerous sections of the *Jamesoni* and *capricornus* beds, till the base of the Middle Lias is reached at the waterfall near the latter place.

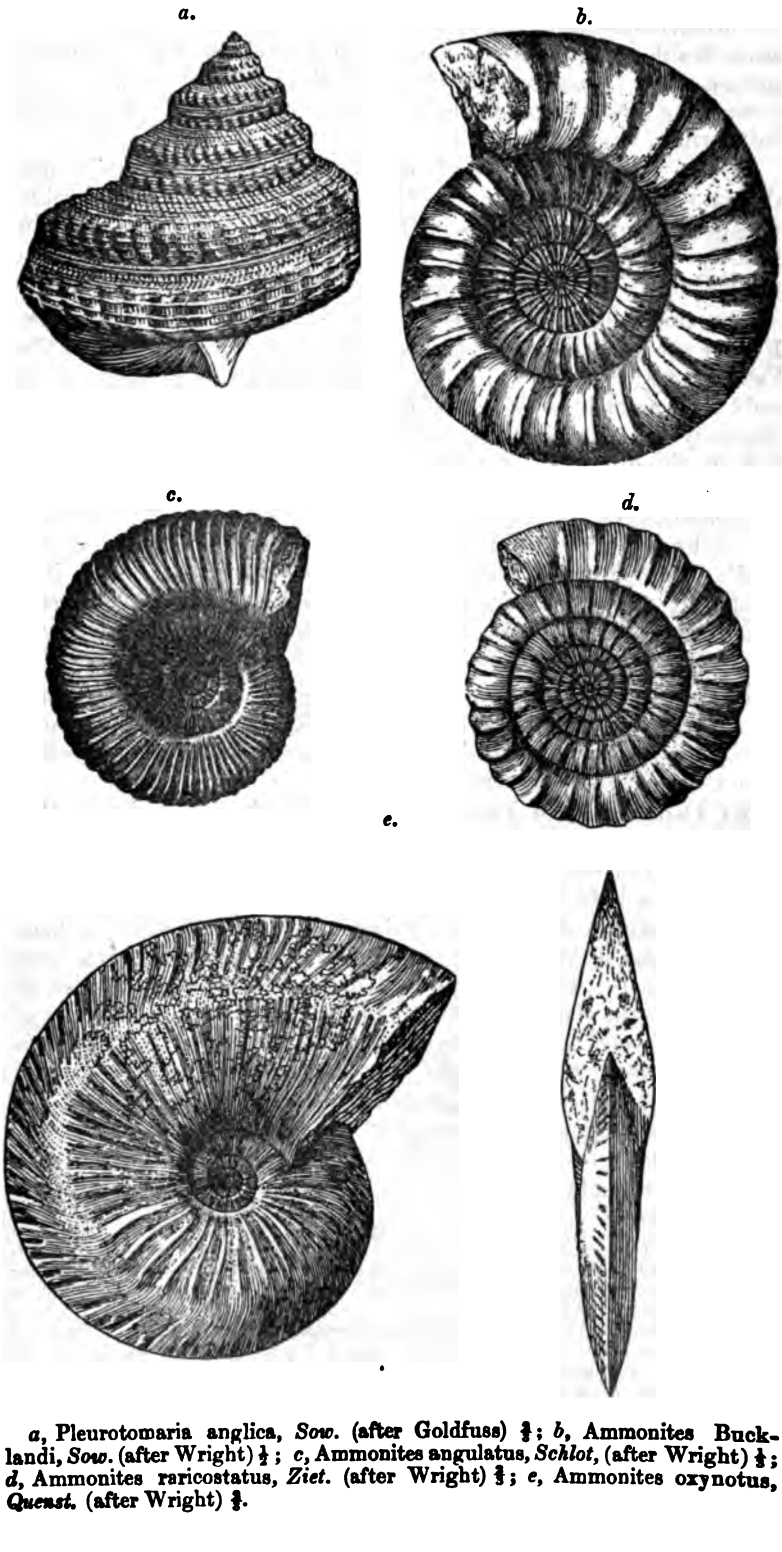
* The higher beds, including the zones of *Am. oxynotus*, *Am. Jamesoni*, and *Am. capricornus*, also crop out on the scars to the north of Redcar, but they are only exposed at very low water, and are so often covered by sand that it is very seldom that they can be seen clearly.

† *See* Memoirs of the Geological Survey, "Geology of North Cleveland," p. 5.

‡ Details are given by G. Barrow, Geology of North Cleveland (Geol. Survey), p. 8. Messrs. Tate and Blake state (p. 84) that this sinking left off in the *Jamesoni* beds at a depth of 240 feet. This would be in the "blue shale, 66 ft. 6 in." But as the "posts," or hard bands of the *oxynotus* series, are all below the soft shales of the *armatus* zone, we think that they should not be included in this latter.

FIG. 2.

Lower Lias Fossils.



a, Pleurotomaria anglica, *Sow.* (after Goldfuss) ⅔; *b*, Ammonites Bucklandi, *Sow.* (after Wright) ½; *c*, Ammonites angulatus, *Schlot*, (after Wright) ⅓; *d*, Ammonites raricostatus, *Ziet.* (after Wright) ⅔; *e*, Ammonites oxynotus, *Quenst.* (after Wright) ⅔.

At the foot of the great escarpment of Cringley and Carlton Moor the higher beds of the Lower Lias are well exposed, as much as 150 feet of shale with ironstone nodules containing *Am. capricornus* being seen at some places.

In the stream above Swainby Mill there is one small section from which Messrs. Tate and Blake obtained *Myoconcha decorata, Modiola scalprum*, with *Gresslya* and *Belemnites*,* but throughout the rest of Scugdale the Lower Lias is completely hidden by superficial deposits.

In the district we are now entering the Lower Lias consists of a mass of dark slightly sandy shales, with hard marly bands in the lower part. These form two distinct outcrops; the upper beds appearing along the steep bank at the foot of the main escarpment and extending in a broad drift-filled hollow some distance to the west, from which the lower marly beds emerge and form a flat table-land above the low escarpment of the Rhætic Beds.

At Whorl Hill the uppermost beds of the Lower Lias are seen close against the fault on the north-east side; and in the railway cutting near the Castle shales with *Am. armatus* and the marly bands below forming the top of the zone of *Am. oxynotus* are exposed, while the zone of *Am. Bucklandi* is represented by some marly bands with *Gryphæa arcuata* which appear in the road near Potto Hill Farm.

Along Limekiln Bank and further west no outcrops are seen at the foot of the hill owing to a thick covering of detritus and Drift, and in Mount Grace Wood only little patches are exposed in the footpaths washed bare by the rain. The junction of the Middle and Lower Lias is very clear under Thimbleby Lodge and in the Cod Beck, and exposures of shale occur for some distance below. Passing down the stream, just at the ford below Ellerbeck Mill, shales with calcareous bands are seen with a considerable number of fossils, the following being recorded by Messrs. Tate and Blake:—

Am. semicostatus.	Lima gigantea.
Am. bisulcatus ?	,, pectinoides.
Nautilus striatus.	Pecten Thiollieri.
Belemnites acutus.	Pinna Hartmanni.
Ostrea [Gryphæa] arcuata.	Unicardium cardioides.
Cardinia crassiuscula.	Lucina limbata.
,, Listeri.	Cidaris Edwardsii.
Lima succincta.	

Further down the stream, in the neighbourhood of Foxton, there are several exposures in the Lower Lias, the best of which are in Foxton Wood. A few obscure exposures are seen in the moat at Sigston Castle, in the road at the Manor House, and further north in the little stream at Willowtree House, the latter being in rather higher beds than the other sections.

Between the main escarpment and the faulted outlier on which the village of Borrowby stands there are no exposures of Lower

* Yorkshire Lias, p. 99.

Lias, but to the west of the latter hill they are fairly numerous. In the woods under Landmoth the calcareous bands with *Gryphæa arcuata* are frequently seen, resting in one place against the Jet-rock of the Upper Lias.

To the west of the Cod Beck is a low flattish plateau formed of these harder bands of the Lower Lias. The beds beneath form the upper part of the low hill facing Northallerton and Thirsk, and these beds are seen at intervals along the hill. Commencing at Hallikeld Farm, platy shales with fragments of calcareous bands containing *Ostrea liassica* crop out just south of the house; and the lowest beds of Lias are exposed at Harrogate, Dibdale, Crosby Cote, and Thornton-le-Beans.

At North Kilvington, just to the east of Spittle Bridge, a thin band of hard limestone is seen dipping north; and further up this stream, near Crake Bank, is a small outcrop of soft shale containing small specimens of *Ammonites armatus.* Further south another siliceous limestone, similar to the above, is seen in Whitelas Beck near Grizzle Field House, north of Feliskirk Lane.

Some distance north of Thirsk the outcrop of the lowest beds of the Lias turns eastwards, but is obscured by Drift as far as Plump Bank; where, in laying the pipes for the water supply of Thirsk, shales with the thin *Ostrea liassica* limestones were turned up on the summit of the hill; while fragments of the *Pleuromya* limestone which are scattered about, would seem to mark the top of the Rhætic Beds.

The paper shales with *Ostrea liassica* were proved in the wells at Bagby, the small hill immediately to the west being the escarpment of the Rhætic Beds veiled by Drift. The same shales may be seen in a ditch in Thirkleby Park, close to the road opposite Stockhill Green.

The lower shale beds are also met with in the cellars at the Hall, and in the beck at Great Thirkleby.

A little further south a great fault, having a throw of over 700 feet, shifts the outcrop of these beds some miles to the west. Barf Hill being composed of Middle Lias the upper limit of the Lower Lias is evidently at the western foot of it. The only other evidence of these beds between the faults is seen in the Swale below Topcliffe, where shale with hard calcareous bands crop out on the edge of the river, and the chief fossils are *Lima gigantea* and *Gryphæa arcuata;* so that we are still some distance above the base.*

South of the long strip of higher beds, let down between the two great Coxwold faults, the outcrop of the several divisions of the Lias is in many places hidden by the thick covering of Drift and Alluvium; and the several small faults which have broken up the beds have rendered the stratigraphy somewhat intricate.

From the position of the Keuper Marl and Rhætic Beds at Sessay, and the Middle Lias at Hutton Sessay and Thormanby, it is evident that the Lower Lias must come on between these places,

* Messrs. Tate and Blake (p. 51) also record *Lima hettangiensis, Lima pectinoides, Cardinia ovalis,* and *Cardinia Listeri,* from this place

although it has not been met with to our knowledge anywhere in this area.

At Carlton Husthwaite "grey shales" are said to be met with at a depth of 12 yards, but there is not much evidence as to what the shales are. The first place that the Lower Lias is really exposed is in the railway cutting near Husthwaite Station. There is not much of the bed seen here, but the outcrop along the valley towards Coxwold may be easily made out by the position of the Middle Lias in the bank above.

In the country to the south towards Easingwold the position of the Lower Lias is even more obscure, and its outcrop can only be inferred by tracing the beds above.

At Easingwold Messrs. Tate and Blake record the following fossils *Cardium oxynoti*, *Pleuromya* sp., *Belemnites araris*, *Rhynchonella variabilis*, *Cucullæa Münsteri*, *Arca* sp., *Ostrea* sp., *Chemnitzia Blainvillei* with marls and sulphurous nodules, which seems to point to an outcrop of the *Jamesoni*-zone;* it is evident that there is a considerable fault here as the lower part of the town stands on Keuper Marl, Rhætic Beds, and quite the lowest beds of the Lias. East of this fault below Crayke the Lower Lias forms a prominent feature for some little distance; which, except for the interruption of a second fault at Stillington, may be followed by Farlington to Sheriff Hutton, although the covering of Boulder Clay is so thick that there are very few places at which the beds themselves can be seen.

On the little hill to the south of Stillington thin limestones with *Pleuromya* and *Ostrea liassica* are scattered about in the fields; while the Tea-Green Marls at the base of the Rhætic Beds were met with in a well just below†. There are also traces of these beds along the hillside by Cornbrough and West Lilling, but the first real section in them is in the deep road cutting to the north of Sheriff Hutton, where are dark blue shales with *Gryphæa obliquata*, and thin limestone with *Pleuromya*.

The next section is in the railway cutting about half a mile beyond Barton Hill Station, where the basement beds of the Lias, containing *Ammonites angulatus*, *Ostrea irregularis*, *Gryphæa arcuata*, &c. are well exposed.

In the large faulted inlier to the north of this range of hills the Lower Lias is almost entirely buried by Boulder Clay, only quite the upper portion being seen below the Middle Lias feature by Brandsby and Terrington.

Beyond the River Derwent the covering of Boulder Clay begins to disappear, and sections in the Lower Lias become much more frequent, these beds being well seen in Howsham Wood and along the hillsides by Acklam, Leppington, Kirkby Underdale, and Garrowby.

These sections are all in the lower beds, principally in the zones of *Am. Bucklandi* and *Am. angulatus*; the higher zones have

* Yorkshire Lias, p. 85.

† See Explanation of Quarter-Sheet 93 N.E. (Geol. Survey), p. 6.

thinned out or become very obscure, but they are not lost by the unconformity of the Oolite as Messrs. Tate and Blake have supposed.

In Bugthorpe Beck and at Garrowby the limestone bands are very well seen, but the extension of the tongue of Lias to the north of Bugthorpe is not so clear, from the thick covering of Boulder Clay. South of Garrowby the Lower Lias forms the steep bank at the foot of the Chalk Wolds, and, being entirely free from Drift, the evidence for its outcrop is very clear. The limestone bands here are thicker and more crystalline, and have been quarried for road-stone, but they do not form a very good material for that purpose.

From the excavation near Ridings Beck the following fossils were obtained:—*Extracrinus* (*Pentacrinus*) *britannicus*, *Gryphæa arcuata*, *Lima gigantea*, *L. pectinoides*, *Pleuromya* (*Myacites*) *costata ?*, *Ammonites angulatus*, *Am. bisulcatus*, and *Am. Maugenesti ?*.

In this region the petrological character of the Lower Lias has considerably changed from what it was in the northern part of the county; instead of consisting principally of shales with thin calcareous bands and ferruginous nodules, the beds here are much more calcareous, and contain, especially in the lower part, strong bands of fossiliferous limestone. These hard bands cause the lower beds to stand out in a bold feature, which forms a fine terrace, both at Pocklington and Market Weighton. South of the latter town in the vicinity of North Cliff these beds have been largely worked for marling the land below, and it is here that we are best able to study their character.

There are about half a dozen or more of these pits, a very detailed account of which has been given by Prof. Blake.* In a general way the beds here exposed may be described as consisting of a thick bed of limestone at the top, full of *Lima gigantea*, *Cardinia Listeri*, and *Ammonites Johnstonii*; below this are softer beds, not generally so well seen, and then beds of limestone again very full of *Ostrea*, forming regular oyster beds; below which there are more shales and soft beds with thin limestones, the lowest beds being full of *Pleuromya crowcombeia* and *Modiola minima*; and below this again more shales with brown sandy bands and fine-grained white limestone resting on the dark laminated shales of the Rhætic Series.

The higher beds of the Lower Lias are not nearly so well exposed as the lower portion, but there are several clay-pits in which these beds are seen, more particularly about Hotham and near Warter. Between the former place and Houghton the "marl" pits are very numerous, the clay containing *Gryphæa arcuata* in great abundance. The total thickness of the Lower Lias is about 100 or 150 feet, but a great portion of the upper beds is frequently hidden by the overlap of the Chalk, so that

* Quart. Journ. Geol. Soc., vol. xxviii. p. 132, and the Yorkshire Lias, p. 38. Also *ante*, p. 33.

very often not more than half this thickness is seen at the outcrop. In the steep bank at Cliff there are nearly 100 feet of these beds, the remaining portion forming the great spread between this place and Newbald.

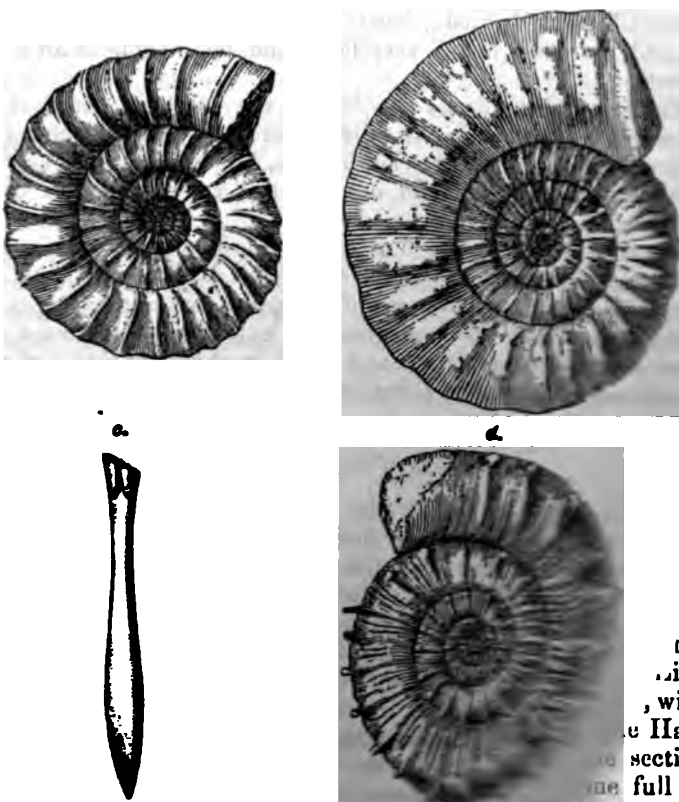
To the north-east of Pocklington the Lower Lias forms the sharp projecting feature just above the town, and is well exposed on the brow of the hill; but the upper part is hidden by a great quantity of chalk débris,* extending over the surface between Wood House and Kildwick Percy Hall.

FIG. 3.

Cephalopoda from the Lower Lias (Upper part), Zones of *Am. Jamesoni* and *Am. capricornus.*

a. b.

c. d.



; ie the Lias. , with e Hall, section full of the road and

a, Ammonites capricornus, *Schlot.* (after Wright) ... genes, *Y. & B.* (after Wright) ½; *c*, ... Phillips) ½; *d*, Ammonites armatus, *Sow.* (after ...

	Ft.	In.
	30	0
...ers	5	0
...t, earthy		
	35	0

Along the steep bank by Deni... seen, although much slipped; and ...

E

* See Memoirs of the Geological Survey ... 94 S.W., and part of 86, p. 32.

Valley, we have the section at the brickyard showing beds high in the series,* while in the stream below Warter Priory there is a good section in the basement beds of the formation.

South of Nunburnholme the Lower Lias makes a good feature to the east of the railway, but there being a thin covering of Drift here, it is not well seen till a little beyond Cleaving Grange, where it is thrown up by a fault, and is exposed in the bank below the road.

In the two valleys running north of Londesbrough Park the Lias extends for some distance, beds low in the series being exposed at Park Farm and elsewhere. In the neighbourhood of Market Weighton the Lias is everywhere well exposed, particularly in the railway cutting and in the beck towards Goodmanham, and also to the south as far as Houghton Hall; beyond it forms the broad spreading terrace of Houghton Moor, between North Cliff and Newbald, but is much hidden by a thick covering of sand, the land being very light, and not having at all a Lias aspect.

The Lower Lias forms the hill to the south of North Cave, where it is exposed in the railway cutting, and the beds may be followed round the hill to South Cave, but beyond this they pass below the alluvial flat, and are not again seen this side of the Humber.

Between North and South Cave the Lower Lias is covered with great quantities of gravel, composed almost entirely of Lias fragments, in which specimens of *Gryphæa arcuata* are especially abundant, showing to how great an extent the Lias must have been exposed to denudation, and also how abundant this particular fossil must have been in those beds.

Inliers of the Lower Lias.

In the valley of the Esk the Lower Lias comes up between Sleights and Grosmont, the finest section being at Blue Scar, where nearly 100 feet of bluish-grey shales with rows of ironstone doggers may be seen. But beyond an occasional specimen of *Am. capricornus* and a few small *Belemnites*, the steepness of the scar is so great that it is difficult to obtain fossils. On the north bank of the river two small sections are exposed in the railway cuttings, close by the stream. The first shows several rows of small flat ironstone doggers in bluish shale; the second, south-west of the former, shows a lighter coloured and more sandy shale, with the basement beds of the Middle Lias above.

A little further up in the bed of the river there are about 50 feet of rather hard, sandy, grey, micaceous shales, with rows of ferruginous nodules, often remarkably spherical. These nodules sometimes contain *Am. capricornus*, but fossils, as a rule, are not common.

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* *Am. armatus* and *Am Macdonnellii* are mentioned by Tate and Blake from this pit; Yorkshire Lias, p. 86.

In Glaisdale there is so much Drift that it is impossible to say whether the Lower Lias occurs. The bottom of the valley is entirely hidden by the Boulder Clay, the depth of which there is no means of measuring.

In Great Fryup the Lower Lias is not reached, but the adjoining dale of Little Fryup cuts about 25 feet into it. There is no good section here, though the earthy shales can be seen in the stream below Crosley Side House.

Danby Dale being quite free from Drift, the grey, earthy shales can be examined at several points in the bed of the stream between Gate House and Honey Bee Nest. The sections are small and no fossils were observed. Not more than 30 feet of the Lower Lias has been cut through.

The sections in Westerdale are much better, and a larger area of Lower Lias is exposed. Immediately west of the fault near Low Farm a low cliff overhanging the stream shows :

	Ft.	In.
Shale with tough doggers - - - - - -	4	0
Line of decayed fossils - - - - - -	0	3
Shale with scattered fossils and tough pyritous doggers -	5	0
Earthy shale with few fossils - - - -	9	0
Total - - - - -	18	3

For a long distance the Lower Lias dips with the stream, so that, though it is exposed for fully three miles in the bottom of Westerdale, there is probably nowhere more than 40 or 50 feet of the upper portion exposed. A furlong east of Hunter's Stile Bridge a scar on the south side of the stream shows :—

	Ft.	In.
Shale with doggers - - - - - - -	20	0
Oolitic ironstone - - - - - - -	0	6
Shale with doggers - - - - -	6	0
Total - - - - -	26	6

The top of this section is very near the base of the Middle Lias. The occurrence of oolitic ironstone is very unusual in the Lower Lias, and at first caused some doubt as to whether the beds might not belong to the Ironstone Series of the Middle Lias. However, earthy shales containing a seam of impure ironstone, with *Ammonites capricornus*, seen in the gill leading to Westerdale Hall, prove that these shales belong to the Lower Lias. The section is poor, but shows an irregular line of earthy ironstone full of fossils, including abundance of *Am. capricornus*. In the road and cliff between the village and the Esk there is :—

		Ft.	In.
Sandy Shale.	Flaggy sandstone, passing into - -	30	0
	Shale, rather sandy, with tough doggers -	5	0
Lower Lias.	Shale, with a few scattered tough, earthy doggers - - - - - -	35	0

Half a mile south-west of Benjy House the oolitic ironstone is again seen in the stream, and from the occurrence of slag heaps a few yards west, and also half a mile north, this ironstone would appear to have been one of the seams anciently worked. At a point a mile further south a change in the dip rapidly carries the beds beneath the stream, and though numerous exposures of the shale are found, there are no good continuous sections. In the eastern branch of Westerdale there is another small inlier.

In Bilsdale the Lower Lias is first seen just south of The Holme, and from this point down the dale small exposures are numerous, especially in the neighbourhood of Chop Gate. Near here, in Raisdale Beck, just above its junction with this dale, is a line of small ironstone nodules containing the usual fossils, which are the lowest beds reached in the dale; in the bank above, shales with *Am. capricornus* are seen. Hollow Bottom Beck near Crookleth flows over these beds for a considerable distance, and the shales are also seen at intervals in the banks of the Seph. In Tripsdale, just below Hagg House, the junction of these beds with the Middle Lias is clearly seen, but further down the stream there are no more clear exposures.

Bransdale cuts about 60 or 70 feet into the Lower Lias, but though there are several small sections of earthy shale, no detailed measurements can be obtained.

Though Farndale shows far more of the Lower Lias than the other inliers, the undulating country these earthy shales form seldom shows sections of more than a few feet. The total thickness of Lower Lias here exposed must be fully 160 feet.

CHAPTER III

THE LIAS (*continued*).

MIDDLE LIAS.

THE Middle Lias is divided into two zones, the upper one that of *Ammonites spinatus*, and the lower that of *Ammonites margaritatus*. Following the plan adopted in the case of the Lower Lias, we commence with a particular account of the zones as they are developed in the Coast-sections.

Account of the Zones in the Middle Lias, as they are exhibited in the Yorkshire Cliffs.

ZONE OF AMMONITES MARGARITATUS.

Synonyms and Foreign Equivalents.—"Blue Marl" (part), W. Smith, Memoir to the Map, 1815; "Staiths beds," Young and Bird, Geol. Survey of the Yorkshire Coast, p. 140, 1822; "The Marlstone Series," Phillips, Geol. of Yorksh., p. 102, 1829; "Marlstone," Williamson, Geol. Trans. 2nd ser., vol. v., p. 224, 1836; "Lias δ, Amaltheenthone," Quenstedt, Flözgebirge, p. 540, 1843; "Marnes à *Ammonites amaltheus* ou *margaritatus*," Marcou, Jura Salinois, p. 50, 1846; "Amaltheenschichten," Strombech, Deutsh. Geol. Gessell., p. 88, 1853; "Macigno d'Aubange" (part), Dumont, Dew. et Chap. Luxemb., p. 273, 1853; "Die obern Schichten des *Am. margaritatus*," Oppel, Juraf., p. 133, 1856; "Oberer Theil des mittleren Lias," Ewald, Sitzung. Berlin Akad., 1859; "Margaritatus-bed," Wright, Quart. Journ. Geol. Soc., vol. xiv., p. 25, 1858; "Zone of *Pecten æquivalvis*," Dumortier, Dep. Jurassique, vol. iii., p. 206, 1869; "Marlstone and Ironstone Series" (part), Phillips, Geol. of Yorksh., 3rd ed., p. 156, 1875; "Zone of *Amaltheus margaritatus*," Wright, Lias Ammonites, p. 93, 1879.

This zone constitutes the main part of the "Sandy Series" or lower division of the Middle Lias; but from the fact of the palæontological zones overlapping the petrological divisions, it is only in a general way that it can be said to represent a definite subdivision.

Messrs. Tate and Blake divide this zone into two portions; the lower consisting of sandstone more or less calcareous, which form the main mass of the Sandy Series; the upper being composed of shales interbedded with ironstone seams and bands of clay-ironstone nodules, which constitute the lower part of the Ironstone Series.

The lower or sandy part of these beds was originally called the "Staiths beds" by Young and Bird, from being well developed and easily accessible at that place; the upper or ironstone portion

and the Ironstone Series of the *Ammonites spinatus* zone above being, for a similar reason, named the "Kettleness beds." Prof. Phillips, adopting the nomenclature of these beds in the South of England, called them the "Marlstone beds;" first of all applying the term to the whole of the Middle Lias, but subsequently modifying it so as to exclude the Ironstone Series.

The zone of *Ammonites margaritatus* first appears on the scars at Peak Steel, from which it is thrown up by the large fault to the top of the cliff, where it may be again seen at the side of the path leading down from the Hall. The beds here contain *Am. margaritatus, Hippopodium ponderosum, Cardium truncatum, Gryphæa cymbium*, and *Dentalium*, but mostly in the form of casts. In skirting round the great amphitheatre of Robin Hood's Bay these beds are mostly hidden by Boulder Clay: but, when they appear again in the cliffs on the north side of the bay, the dip gradually brings them down to the shore at Hawsker Bottoms, where is one of the typical sections of these beds, although they are not so thick as further north. Messrs. Tate and Blake give the following measurements from these cliffs:—

Section of the Margaritatus-*beds, Hawsker Bottoms.*

No.	Petrology.	Thickness. Ft.	In.	Organic Remains.
1	Strong brown iron dogger	0	6	*Monotis cygnipes.*
2	Friable shales - -	0	8	
3	Brown ironstone rough dogger.	0	4	
4	Crumbly laminated shales	1	7	
5	Double knobbly dogger -	0	4	*Gresslya intermedia, Pleuromya costata.*
6	Very finely laminated shale.	1	5	
7	Dogger-sandstone band -	0	5	
8	Dark crumbly shale with occasional doggers.	13	8	
9	Yellow sandy band -	0	5	
10	Black shale - -	0	8	
11	Strong consecutive dogger	0	8	
12	Blue black softish shale with large fossiliferous doggers scattered. -	15	0	*Modiola scalprum, Cardita multicosta, Plicatula spinosa, Pecten æquivalvis, Am. margaritatus, Pleuromya costata, Ceromya petricosa, Protocardium truncatum.*
13	Double consecutive dogger with soft parting.	0	7	*Pecten æquivalvis.*
14	Soft shale - -	6	4	Wood.
15	Fossiliferous dogger, variable, blue shale.	0	10	*Gresslya intermedia, Astarte striato-sulcata. Pecten æquivalvis, Chemnitzia citharella, Leda minor, Belemnites clavatus.*
16	Strong consecutive rough ironstone.	0	6	*Protocardium truncatum.*
17	Dark shales with oysters and comminuted fossils.	1	8	*Gryphæa cymbium.*

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
18	Doggers - - -	0 3	*Protocardium truncatum.*
19	Dark blue speckly shales	2 3	
20	Hard calcareous sandstone with cone-in-cone structure.	0 to 12	*Am. margaritatus.*
21	Dark speckly shales . -	2 0	*Am. margaritatus, Protocardium truncatum, Monotis inæquivalvis, Pecten lunularis.*
22	Hard irregular dogger -	0 6	
23	Light speckly shales -	3 8	*Dentalium giganteum, Protocardium truncatum, Pecten lunularis.*
24	White dogger - -	0 4	
25	Dark blue speckly shales with irregular doggers.	9 10	
26	Thin-bedded, rippled, and laminated yellow sandstone.	1 3	
27	Bluish shales - -	3 6	Wood, calcite.
28	Dogger band - -	0 8	*Protocardium truncatum* (numerous).
29	Hard speckly shale with hard bands, graduating into	4 0	*Protocardium truncatum.*
30	Hard yellow sandstone-rock with layers of oysters.	5 0	*Gryphæa cymbium, Protocardium truncatum.*
31	Hard dark speckly shales with laminated band.	5 8	*Am. margaritatus, Bel. elegans.*
32	Laminated sandy beds -	0 7	
33	Dark speckled shales -	4 8	
34	Strong ironstone dogger -	0 8	*Protocardium truncatum.*
35	Dark speckled shales	0 5	
	Series of oyster and sandstone bands of the *capricornus*-zone.		
	Total -	90 10	

It is very difficult to fix the upper limit of this zone at Hawsker, and we cannot help thinking that Messrs. Tate and Blake have taken it much too high. The three first beds in this part of the section appear to represent the Pecten Seam; if this is the case, it is probable that the beds 9, 10, 11, which form a very conspicuous line in the cliff, are about on the horizon of the Bottom or Avicula Seam, and consequently the first eight beds in the section should be included in the *Am. spinatus* zone. A glance at the comparative sections renders this more apparent.* At Staithes, where these beds come up again and are exposed on the shore and in the cliff, they are very favourably situated for examination, which has enabled Messrs. Tate and Blake to give the very copious list of fossils in the following section:—

* See Plate II., page 124.

thinned out or become very obscure, but they are not lost by the unconformity of the Oolite as Messrs. Tate and Blake have supposed.

In Bugthorpe Beck and at Garrowby the limestone bands are very well seen, but the extension of the tongue of Lias to the north of Bugthorpe is not so clear, from the thick covering of Boulder Clay. South of Garrowby the Lower Lias forms the steep bank at the foot of the Chalk Wolds, and, being entirely free from Drift, the evidence for its outcrop is very clear. The limestone bands here are thicker and more crystalline, and have been quarried for road-stone, but they do not form a very good material for that purpose.

From the excavation near Ridings Beck the following fossils were obtained:—*Extracrinus* (*Pentacrinus*) *britannicus*, *Gryphæa arcuata*, *Lima gigantea*, *L. pectinoides*, *Pleuromya* (*Myacites*) *costata ?*, *Ammonites angulatus*, *Am. bisulcatus*, and *Am. Maugenesti ?*.

In this region the petrological character of the Lower Lias has considerably changed from what it was in the northern part of the county; instead of consisting principally of shales with thin calcareous bands and ferruginous nodules, the beds here are much more calcareous, and contain, especially in the lower part, strong bands of fossiliferous limestone. These hard bands cause the lower beds to stand out in a bold feature, which forms a fine terrace, both at Pocklington and Market Weighton. South of the latter town in the vicinity of North Cliff these beds have been largely worked for marling the land below, and it is here that we are best able to study their character.

There are about half a dozen or more of these pits, a very detailed account of which has been given by Prof. Blake.* In a general way the beds here exposed may be described as consisting of a thick bed of limestone at the top, full of *Lima gigantea*, *Cardinia Listeri*, and *Ammonites Johnstonii;* below this are softer beds, not generally so well seen, and then beds of limestone again very full of *Ostrea*, forming regular oyster beds; below which there are more shales and soft beds with thin limestones, the lowest beds being full of *Pleuromya crowcombeia* and *Modiola minima;* and below this again more shales with brown sandy bands and fine-grained white limestone resting on the dark laminated shales of the Rhætic Series.

The higher beds of the Lower Lias are not nearly so well exposed as the lower portion, but there are several clay-pits in which these beds are seen, more particularly about Hotham and near Warter. Between the former place and Houghton the "marl" pits are very numerous, the clay containing *Gryphæa arcuata* in great abundance. The total thickness of the Lower Lias is about 100 or 150 feet, but a great portion of the upper beds is frequently hidden by the overlap of the Chalk, so that

* Quart. Journ. Geol. Soc., vol. xxviii. p. 132, and the Yorkshire Lias, p. 38. Also *ante*, p. 33.

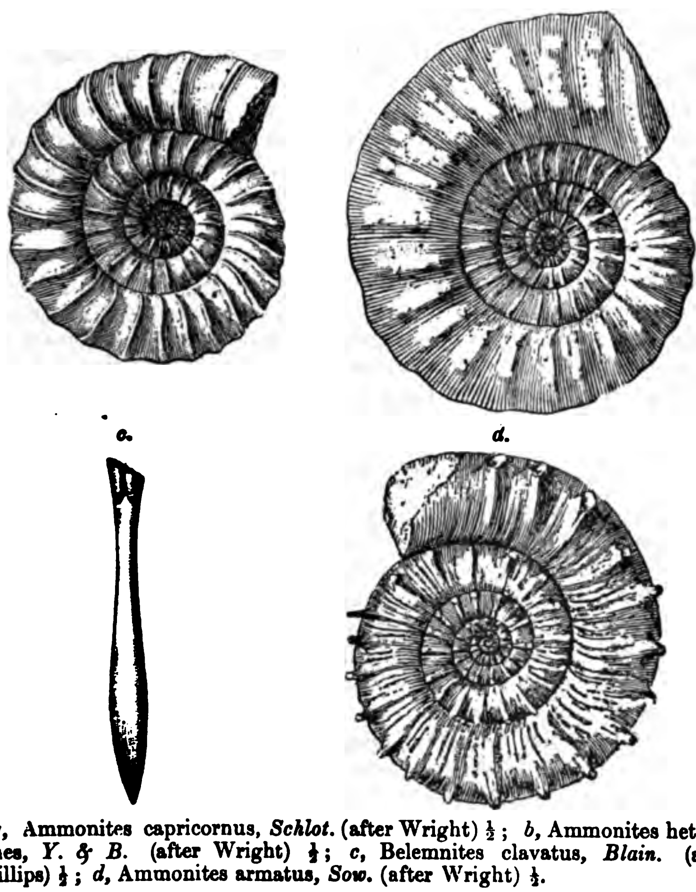
very often not more than half this thickness is seen at the outcrop. In the steep bank at Cliff there are nearly 100 feet of these beds, the remaining portion forming the great spread between this place and Newbald.

To the north-east of Pocklington the Lower Lias forms the sharp projecting feature just above the town, and is well exposed on the brow of the hill; but the upper part is hidden by a great quantity of chalk débris,* extending over the surface between Wood House and Kildwick Percy Hall.

FIG. 3.

Cephalopoda from the Lower Lias (Upper part), Zones of *Am. Jamesoni* and *Am. capricornus.*

a. *b.*



a, Ammonites capricornus, *Schlot.* (after Wright) $\frac{1}{2}$; *b*, Ammonites heterogenes, *Y. & B.* (after Wright) $\frac{1}{2}$; *c*, Belemnites clavatus, *Blain.* (after Phillips) $\frac{1}{2}$; *d*, Ammonites armatus, *Sow.* (after Wright) $\frac{1}{2}$.

Along the steep bank by Denison's Wood the beds are well seen, although much slipped; and passing round into the Warter

* *See* Memoirs of the Geological Survey. Explanation of Quarter-Sheets 93 S.E., 94 S.W., and part of 86, p. 32.

Valley, we have the section at the brickyard showing beds high in the series,* while in the stream below Warter Priory there is a good section in the basement beds of the formation.

South of Nunburnholme the Lower Lias makes a good feature to the east of the railway, but there being a thin covering of Drift here, it is not well seen till a little beyond Cleaving Grange, where it is thrown up by a fault, and is exposed in the bank below the road.

In the two valleys running north of Londesbrough Park the Lias extends for some distance, beds low in the series being exposed at Park Farm and elsewhere. In the neighbourhood of Market Weighton the Lias is everywhere well exposed, particularly in the railway cutting and in the beck towards Goodmanham, and also to the south as far as Houghton Hall; beyond it forms the broad spreading terrace of Houghton Moor, between North Cliff and Newbald, but is much hidden by a thick covering of sand, the land being very light, and not having at all a Lias aspect.

The Lower Lias forms the hill to the south of North Cave, where it is exposed in the railway cutting, and the beds may be followed round the hill to South Cave, but beyond this they pass below the alluvial flat, and are not again seen this side of the Humber.

Between North and South Cave the Lower Lias is covered with great quantities of gravel, composed almost entirely of Lias fragments, in which specimens of *Gryphæa arcuata* are especially abundant, showing to how great an extent the Lias must have been exposed to denudation, and also how abundant this particular fossil must have been in those beds.

Inliers of the Lower Lias.

In the valley of the Esk the Lower Lias comes up between Sleights and Grosmont, the finest section being at Blue Scar, where nearly 100 feet of bluish-grey shales with rows of ironstone doggers may be seen. But beyond an occasional specimen of *Am. capricornus* and a few small *Belemnites*, the steepness of the scar is so great that it is difficult to obtain fossils. On the north bank of the river two small sections are exposed in the railway cuttings, close by the stream. The first shows several rows of small flat ironstone doggers in bluish shale; the second, south-west of the former, shows a lighter coloured and more sandy shale, with the basement beds of the Middle Lias above.

A little further up in the bed of the river there are about 50 feet of rather hard, sandy, grey, micaceous shales, with rows of ferruginous nodules, often remarkably spherical. These nodules sometimes contain *Am. capricornus*, but fossils, as a rule, are not common.

* *Am. armatus* and *Am Macdonnellii* are mentioned by Tate and Blake from this pit; Yorkshire Lias, p. 86.

In Glaisdale there is so much Drift that it is impossible to say whether the Lower Lias occurs. The bottom of the valley is entirely hidden by the Boulder Clay, the depth of which there is no means of measuring.

In Great Fryup the Lower Lias is not reached, but the adjoining dale of Little Fryup cuts about 25 feet into it. There is no good section here, though the earthy shales can be seen in the stream below Crosley Side House.

Danby Dale being quite free from Drift, the grey, earthy shales can be examined at several points in the bed of the stream between Gate House and Honey Bee Nest. The sections are small and no fossils were observed. Not more than 30 feet of the Lower Lias has been cut through.

The sections in Westerdale are much better, and a larger area of Lower Lias is exposed. Immediately west of the fault near Low Farm a low cliff overhanging the stream shows:

	Ft.	In.
Shale with tough doggers - - - - - -	4	0
Line of decayed fossils - - - - - -	0	3
Shale with scattered fossils and tough pyritous doggers -	5	0
Earthy shale with few fossils - - - -	9	0
Total - - - - -	18	3

For a long distance the Lower Lias dips with the stream, so that, though it is exposed for fully three miles in the bottom of Westerdale, there is probably nowhere more than 40 or 50 feet of the upper portion exposed. A furlong east of Hunter's Stile Bridge a scar on the south side of the stream shows:—

	Ft.	In.
Shale with doggers - - - - - - -	20	0
Oolitic ironstone - - - - - - -	0	6
Shale with doggers - - - - -	6	0
Total - - - - -	26	6

The top of this section is very near the base of the Middle Lias. The occurrence of oolitic ironstone is very unusual in the Lower Lias, and at first caused some doubt as to whether the beds might not belong to the Ironstone Series of the Middle Lias. However, earthy shales containing a seam of impure ironstone, with *Ammonites capricornus*, seen in the gill leading to Westerdale Hall, prove that these shales belong to the Lower Lias. The section is poor, but shows an irregular line of earthy ironstone full of fossils, including abundance of *Am. capricornus*. In the road and cliff between the village and the Esk there is:—

		Ft.	In.
Sandy Shale.	Flaggy sandstone, passing into - -	30	0
	Shale, rather sandy, with tough doggers -	5	0
Lower Lias.	Shale, with a few scattered tough, earthy doggers - - - - -	35	0

Half a mile south-west of Benjy House the oolitic ironstone is again seen in the stream, and from the occurrence of slag heaps a few yards west, and also half a mile north, this ironstone would appear to have been one of the seams anciently worked. At a point a mile further south a change in the dip rapidly carries the beds beneath the stream, and though numerous exposures of the shale are found, there are no good continuous sections. In the eastern branch of Westerdale there is another small inlier.

In Bilsdale the Lower Lias is first seen just south of The Holme, and from this point down the dale small exposures are numerous, especially in the neighbourhood of Chop Gate. Near here, in Raisdale Beck, just above its junction with this dale, is a line of small ironstone nodules containing the usual fossils, which are the lowest beds reached in the dale; in the bank above, shales with *Am. capricornus* are seen. Hollow Bottom Beck near Crookleth flows over these beds for a considerable distance, and the shales are also seen at intervals in the banks of the Seph. In Tripsdale, just below Hagg House, the junction of these beds with the Middle Lias is clearly seen, but further down the stream there are no more clear exposures.

Bransdale cuts about 60 or 70 feet into the Lower Lias, but though there are several small sections of earthy shale, no detailed measurements can be obtained.

Though Farndale shows far more of the Lower Lias than the other inliers, the undulating country these earthy shales form seldom shows sections of more than a few feet. The total thickness of Lower Lias here exposed must be fully 160 feet.

CHAPTER III

THE LIAS (*continued*).

MIDDLE LIAS.

THE Middle Lias is divided into two zones, the upper one that of *Ammonites spinatus*, and the lower that of *Ammonites margaritatus*. Following the plan adopted in the case of the Lower Lias, we commence with a particular account of the zones as they are developed in the Coast-sections.

Account of the Zones in the Middle Lias, as they are exhibited in the Yorkshire Cliffs.

ZONE OF AMMONITES MARGARITATUS.

Synonyms and Foreign Equivalents.—"Blue Marl" (part), W. Smith, Memoir to the Map, 1815; "Staiths beds," Young and Bird, Geol. Survey of the Yorkshire Coast, p. 140, 1822; "The Marlstone Series," Phillips, Geol. of Yorksh., p. 102, 1829; "Marlstone," Williamson, Geol. Trans. 2nd ser., vol. v., p. 224, 1836; "Lias δ, Amaltheenthone," Quenstedt, Flözgebirge, p. 540, 1843; "Marnes à *Ammonites amaltheus* ou *margaritatus*," Marcou, Jura Salinois, p. 50, 1846; "Amaltheenschichten," Strombech, Deutsh. Geol. Gessell., p. 88, 1853; "Macigno d'Aubange" (part), Dumont, Dew. et Chap. Luxemb., p. 273, 1853; "Die obern Schichten des *Am. margaritatus*," Oppel, Juraf., p. 133, 1856; "Oberer Theil des mittleren Lias," Ewald, Sitzung. Berlin Akad., 1859; "Margaritatus-bed," Wright, Quart. Journ. Geol. Soc., vol. xiv., p. 25, 1858; "Zone of *Pecten æquivalvis*," Dumortier, Dep. Jurassique, vol. iii., p. 206, 1869; "Marlstone and Ironstone Series" (part), Phillips, Geol. of Yorksh., 3rd ed., p. 156, 1875; "Zone of *Amaltheus margaritatus*," Wright, Lias Ammonites, p. 93, 1879.

This zone constitutes the main part of the "Sandy Series" or lower division of the Middle Lias; but from the fact of the palæontological zones overlapping the petrological divisions, it is only in a general way that it can be said to represent a definite subdivision.

Messrs. Tate and Blake divide this zone into two portions; the lower consisting of sandstone more or less calcareous, which form the main mass of the Sandy Series; the upper being composed of shales interbedded with ironstone seams and bands of clay-ironstone nodules, which constitute the lower part of the Ironstone Series.

The lower or sandy part of these beds was originally called the "Staiths beds" by Young and Bird, from being well developed and easily accessible at that place; the upper or ironstone portion

and the Ironstone Series of the *Ammonites spinatus* zone above being, for a similar reason, named the "Kettleness beds." Prof. Phillips, adopting the nomenclature of these beds in the South of England, called them the "Marlstone beds;" first of all applying the term to the whole of the Middle Lias, but subsequently modifying it so as to exclude the Ironstone Series.

The zone of *Ammonites margaritatus* first appears on the scars at Peak Steel, from which it is thrown up by the large fault to the top of the cliff, where it may be again seen at the side of the path leading down from the Hall. The beds here contain *Am. margaritatus, Hippopodium ponderosum, Cardium truncatum, Gryphæa cymbium*, and *Dentalium*, but mostly in the form of casts. In skirting round the great amphitheatre of Robin Hood's Bay these beds are mostly hidden by Boulder Clay; but, when they appear again in the cliffs on the north side of the bay, the dip gradually brings them down to the shore at Hawsker Bottoms, where is one of the typical sections of these beds, although they are not so thick as further north. Messrs. Tate and Blake give the following measurements from these cliffs:—

Section of the Margaritatus-*beds, Hawsker Bottoms.*

No.	Petrology.	Thickness. Ft.	In.	Organic Remains.
1	Strong brown iron dogger	0	6	*Monotis cygnipes.*
2	Friable shales - -	0	8	
3	Brown ironstone rough dogger.	0	4	
4	Crumbly laminated shales	1	7	
5	Double knobbly dogger -	0	4	*Gresslya intermedia, Pleuromya costata.*
6	Very finely laminated shale.	1	5	
7	Dogger-sandstone band -	0	5	
8	Dark crumbly shale with occasional doggers.	13	8	
9	Yellow sandy band -	0	5	
10	Black shale - -	0	8	
11	Strong consecutive dogger	0	8	
12	Blue black softish shale with large fossiliterous doggers scattered. -	15	0	*Modiola scalprum, Cardita multicosta, Plicatula spinosa, Pecten æquivalvis, Am. margaritatus, Pleuromya costata, Ceromya petricosa, Protocardium truncatum.*
13	Double consecutive dogger with soft parting.	0	7	*Pecten æquivalvis.*
14	Soft shale - -	6	4	Wood.
15	Fossiliferous dogger, variable, blue shale.	0	10	*Gresslya intermedia, Astarte striato-sulcata. Pecten æquivalvis, Chemnitzia citharella, Leda minor, Belemnites clavatus.*
16	Strong consecutive rough ironstone.	0	6	*Protocardium truncatum.*
17	Dark shales with oysters and comminuted fossils.	1	8	*Gryphæa cymbium.*

No.	Petrology.*	Thickness. Ft. In.	Organic Remains.
18	Doggers - - -	0 3	*Protocardium truncatum.*
19	Dark blue speckly shales	2 3	
20	Hard calcareous sandstone with cone-in-cone structure.	0 to 12	*Am. margaritatus.*
21	Dark speckly shales . -	2 0	*Am. margaritatus, Protocardium truncatum, Monotis inæquivalvis, Pecten lunularis.*
22	Hard irregular dogger -	0 6	
23	Light speckly shales -	3 8	*Dentalium giganteum, Protocardium truncatum, Pecten lunularis.*
24	White dogger - -	0 4	
25	Dark blue speckly shales with irregular doggers.	9 10	
26	Thin-bedded, rippled, and laminated yellow sandstone.	1 3	
27	Bluish shales - -	3 6	Wood, calcite.
28	Dogger band - -	0 8	*Protocardium truncatum* (numerous).
29	Hard speckly shale with hard bands, graduating into	4 0	*Protocardium truncatum.*
30	Hard yellow sandstone-rock with layers of oysters.	5 0	*Gryphæa cymbium, Protocardium truncatum.*
31	Hard dark speckly shales with laminated band.	5 8	*Am. margaritatus, Bel. elegans.*
32	Laminated sandy beds -	0 7	
33	Dark speckled shales -	4 8	
34	Strong ironstone dogger -	0 8	*Protocardium truncatum.*
35	Dark speckled shales	0 5	
	Series of oyster and sandstone bands of the *capricornus*-zone.		
	Total -	90 10	

It is very difficult to fix the upper limit of this zone at Hawsker, and we cannot help thinking that Messrs. Tate and Blake have taken it much too high. The three first beds in this part of the section appear to represent the Pecten Seam; if this is the case, it is probable that the beds 9, 10, 11, which form a very conspicuous line in the cliff, are about on the horizon of the Bottom or Avicula Seam, and consequently the first eight beds in the section should be included in the *Am. spinatus* zone. A glance at the comparative sections renders this more apparent.* At Staithes, where these beds come up again and are exposed on the shore and in the cliff, they are very favourably situated for examination, which has enabled Messrs. Tate and Blake to give the very copious list of fossils in the following section:—

* See Plate II., page 124.

Section of the Margaritatus-*beds, Staithes.*

No.	Petrology.	Thickness. Ft.	In.	Organic Remains.
	Zone of *Ammonites spinatus.*			
1	Bottom seam of impure ironstone; shells enveloped in a calcareous matrix.	2	0	*Ammonites margaritatus, Belemnites, Pecten æquivalvis, Gryphæa cymbium, Cypricardia cucullata.*
2	Blue marly shale; top surface crowded with *Belemnites.* Blue shale -	4	3	*Am. margaritatus, Belemnites, Pecten æquivalvis,* Wood.
3	Fine grained argillaceous limestone.	0	1	
4	Blue shale - -	5	5	
5	Band of clay-ironstone slightly speckled with white grains, forms a scar on the flat shore.	0	10	*Am. margaritatus, Protocardium truncatum, Monotis cygnipes.*
6	Black splintery shale -	9	8	
7	Oval argillaceous limestone doggers. Black splintery shale -	5	4	
8	Clay-ironstone in two blocks, weathering brick-red.	2	0	*Am. margaritatus, Gryphæa cymbium, Protocardium truncatum.*
9	Shale - - -	1	0	
10	Argillaceous limestone dogger.	0	8	
11	Shale - - -	0	2	*Gryphæa cymbium.*
12	Small doggers - -	0	1½	
13	Shell-bed - -	0	1½	Belemnites and oysters.
14	Sandy shale with scattered doggers.	2	11	*Gresslya Seebachii.*
15	Blue shale with doggers and shell-masses.	6	0	*Gresslya Seebachii, Protocardium truncatum, Pecten æquivalvis, Macrodon intermedius.*
16	Shale with doggers and shell-masses.	10	6	*Am. margaritatus, Am. capricornus* (very small), *Discohelix aratus, Dentalium elongatum, Chemnitzia Blainvillei, C. citharella, Eucyclus undulatus, Arcomya arcacea, Monotis inæquivalvis, Protocardium truncatum, Cardita multicosta, Cardinia lævis, C. antiqua, Cypricardia cucullata, Ceromya petricosa, Goniomya hybrida, Hippopodium ponderosum, Leda minor, L. galathea, L. graphica, Limea acuticosta, Pecten æquivalvis, P. lunularis, Macrodon intermedius, Thracia grotiana, Terebratula punctata.*
17	Dogger-bands - -	0	4	
18	Marly shale - -	8	0	
19	Sandy shale and doggers	7	0	
20	Calciferous sandstone -	0	8	
21	Sandy marls - -	2	9	*Gresslyæ.*
22	Dogger-band - -	0	3	
23	Sandy marls - -	2	0	
24	Blue limestone - -	1	0	

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
25	Striped sandy shales with fossiliferous doggers and thin sandstones.	17 2	*Am. margaritatus*, *Chemnitzia Blainvillei*, *Protocardium truncatum*.
26	Reddish sandstone with bands of fossils.	2 6	*Dentalium giganteum*, *Protocardium truncatum*, *Lima Hermanni*, *Monotis cygnipes*, &c.
27	Grey sandstone and flags, false-bedded.	6 6	
28	Calciferous sandstones -	6 2	
29	Soft marly sandstone and thin calciferous sandstone bands.	4 0	(Base of ciiff.)
30*	Sandy shales - - Impure limestone bands - Grey marly sandstone - Blue micaceous sandstone	10 0	(Exposed on the shore at low tide.) *Protocardium truncatum*, *Pecten æquivalvis*, *Belemnites virgatus*.
	Total -	119 0	

Messrs. Tate and Blake have mistaken the position of the Bottom Seam in this section. No. 1 is really the Two-Foot Seam, and the Bottom or Avicula Seam, which these authors take as the upper limit of the *margaritatus*-beds, does not occur until we get down to No. 8, consequently the upper 27 ft. 7 in. belong to the *spinatus*-beds. It will thus be seen that *Ammonites margaritatus* ascends considerably higher than what is usually taken as the limit of this zone. In this section the Sandy Series would appear to commence with No. 25.

At Hummersea Messrs. Tate and Blake divide these beds into two series, in the following manner:—

Section of the Margaritatus-*beds*, *Hummersea.*

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
	Ammonites spinatus beds.		
	Upper *Margaritatus* Beds.		
1	Bottom seam of ironstone	1 4	
2	Black laminated shale -	8 4	
3	Clay-ironstone, slightly oolitic.	0 4	
4	Black shale - -	10 2	
5	Blue argillaceous limestone.	0 1½	
6	Black laminated shale -	4 0	
7	Clay ironstone - -	0 2	
8	Shale - - -	0 8	

* These beds are not included by Messrs. Tate and Blake in their section, the relative position of them to the beds above being somewhat doubtful.

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
9	Nodular band of blue ferro-argillaceous limestone, speckled with white grains.	0 9	
10	Shale - - -	0 10	
11	Oval doggers of argillaceous limestone.	0 4	
12	Tough micaceous shales -	4 10	
13	Small doggers of argillaceous limestone. Tough micaceous shales -	17 0	*Pecten lunularis, Limea acuticosta, Gervillia ærosa, Leda subovalis.*
14	Indurated sandy shale -	1 0	
15	Blue hard sandy shale -	8 7	*Leda graphica, Pecten lunularis.*
16	Grey oval septariate nodules.	0 4	
17	Hard sandy shales -	3 9	
18	Calcifero-argillaceous balls	0 3	
	Lower *Margaritatus* Beds.		
19	Blue shaly sandstone -	2 6	*Protocardium truncatum.*
20	Blue shaly calciferous sandstone.	0 7	
21	Hard sandy shales -	1 4	
22	Very hard blue calciferous sandstone in two bands.	1 2	
23	Rubbly sandstone.	6 0	
24	Hard grey fine-grained flaggy sandstone.	4 2	
25	Doggers of blue limestone - - - Marly sand-rock -	5 3	
26	Yellow and blue thinly-bedded micaceous sandstone.	4 5	
27	Marly sand-rock - -	3 3	
28	Coarse yellow-sandstone	2 9	
29	Marly sand-rock - -	1 8	*Gresslya Seebachii.*
30	Dark red, hard, ferruginous sandstone.	0 8	
31	Hard marly and flaggy sandstones.	3 2	
32	Subcrystalline calciferous sandstone.	2 6	
33	Blue flaggy calciferous sandstone.	1 5	*Am. margaritatus, Dentalium giganteum, Modiola scalprum, Pecten æquivalvis, P. substriatus, Gryphæa cymbium, Protocardium truncatum, Monotis inæquivalvis, Leda minor, Rhynchonella calcicosta.*
34	Blue calciferous sandstone	0 5	
	Total thickness -	109 0	
	Zone of *Ammonites capricornus.*		

In this section the apparent paucity of organic remains arises from the fact of the beds forming a nearly perpendicular cliff which it is very difficult to examine properly.

Fossils from the Zone of Am. margaritatus.

ECHINODERMATA.

Cidaris Edwardsii, *Wright.*
Ophioderma Milleri, *Phil.*
Extracrinus subangularis ?, *Miller.*
Pentacrinus gracilis, *Charlesworth.*

ANNELIDA.

Ditrupa circinata, *Tate.*
—— quinquesulcata, *Münster.*
Serpula limax, *Goldf.*

BRACHIOPODA.

Rhynchonella acuta, *Sow.*
—— calcicosta, *Quenst.*
—— tetrahedra, *Sow.*
Spiriferina rostrata, *Schlot.*
—— Tessoni, *Dav.*
Terebratula punctata, *Sow.*

LAMELLIBRANCHIATA.

Anomia numismalis, *Quenst.*
Avicula calva, *Schlönb.*
—— cygnipes, *Y. & B.*
—— inæquivalvis, *Sow.*
Gervillia ærosa, *Simp.*
Inoceramus substriatus, *Münster.*
Lima eucharis, *d'Orb.*
—— Hermanni, *Voltz.*
—— succincta, *Schlot.*
Limea acuticosta, *Münster.*
Gryphæa cymbium, var. depressa, *Phil.*
Ostrea submargaritacea, *Brauns.*
Pecten æquivalvis, *Sow.*
—— calvus, *Goldf.*
—— lunularis, *Röm.*
—— substriatus, *Röm.*
Plicatula calva, *Desl.*
—— spinosa, *Sow.*
Arcomya arcacea, *Seebach.*
—— hispida, *Simp.*
Astarte striato-sulcata, *Röm.*
Cardinia antiqua, *Phil.*
—— lævis, *Y. & B.*
Cardita multicostata, *Phil.*
Cardium truncatum, *Sow.*
Ceromya petricosa, *Simp.*
Cypricardia cucullata, *Münster.*
Goniomya hybrida, *Münster.*
Gresslya intermedia, *Simp.*
—— lunulata, *Tate.*
—— Seebachii, *Brauns.*
Hippopodium ponderosum, *Sow.*
Leda galathea, *d'Orb.*
—— graphica, *Tate.*
—— minor, *Simp.*
Macrodon Buckmani, *Richardson.*
—— intermedius, *Simp.*
Modiola numismalis, *Oppel.*
—— scalprum, *Sow.*
—— subcancellata, *Buvig.*
—— Thiollierei, *Dum.*
Pholadomya ambigua, *Sow.*
Pleuromya costata. *Y. & B.*
—— granata, *Simp.*
—— mundula, *Tate.*
Tellina fabalis, *Simp.*
Thracia Grotiani, *Brauns.*

SCAPHOPODA.

Dentalium elongatum, *Münster.*
Dentalium giganteum, *Phil.*

GASTEROPODA.

Actæonina ilminsterensis, *Moore.*
Chemnitzia Blainvillei, *Münster.*
—— citharella, *Tate.*
—— nuda, *Münster.*
—— semitecta, *Tate.*
Cryptænia expansa, *Sow.*
Discohelix aratus, *Tate.*
—— bellulus, *Tate.*
Eucyclus cingendus, *Tate.*
—— undulatus, *Phil.*
Littorina clevelandica, *Tate.*
Turbo cyclostoma, *Benz.*

CEPHALOPODA.

Ammonites capricornus, *Schlot.*
—— ferrugineus, *Simp.*
—— fimbriatus, *Sow.*
—— margaritatus, *Mont.*
—— nitescens, *Y. & B.*
—— spinatus, *Brug.*
Belemnites apicicurvatus, *Blain.*
Belemnites breviformis, *Voltz.*
—— clavatus, *Blain.*
—— cylindricus, *Simp.*
—— longiformis, *Blake.*
—— Milleri, *Phil.*
—— virgatus, *Mayer.*

PISCES.

Tooth.

Zone of Ammonites spinatus.

Synonyms and Foreign Equivalents.—"Kettleness beds," Young and Bird, Geol. Survey of the Yorkshire Coast, p. 139, 1822; "The Ironstone series," Phillips, Geol. of Yorksh., p. 102, 1829; "Amaltheenthone" (upper part), Quenstedt, Flözgebirge, p. 540, 1843; "Marnes à Plicatules," Marcou, Jura Salinois, p. 51, 1846; "Region des *Ammonites costatus*," Oppel, Mittl. Lias Schwabens, p. 23, 1853; "Die Schichten des *Ammonites spinatus*," Oppel, Juraformation, p. 138, 1856; "Spinatus-bed," Wright, Quart. Journ. Geol. Soc., vol. xiv., p. 25, 1858; "Thone mit *Amm. spinatus*," Ewald, Sitz. d. Berlin Akad, p. 349, 1859; "Horizont. von *Amm. spinatus*," Wagener, Lias von Falkenhagen, 1860; "Zone of *Amm. spinatus*," Wright, Fossil Asteroidea, Pal. Soc., 1863; "Zone a *Pecten æquivalvis*" (upper part), Dumortier, Dep. Jura, vol. iii., p. 213, 1869; "Zone of *Amaltheus spinatus*," Wright, Lias Ammonites, p. 103, 1879.

This zone is sometimes considered as synonymous with the Ironstone Series, but strictly speaking it only includes the upper portion of those beds. Messrs. Tate and Blake draw the line between this zone and that of *Ammonites margaritatus* at the top of the "Avicula" or "Bottom Seam" of ironstone, consequently it includes only about two-thirds of the Ironstone Series.

The beds comprised within this subdivision, like the upper part of the *margaritatus* zone, consist of argillaceous shales with bands of ironstone. The principal of these are the Cleveland Main Seam, the Pecten Seam, the Two-Foot Seam, and quite at the base the Avicula or Bottom Seam which palæontologically belongs to the zone below. Of these seams the first two become united in the extreme north-west, but split up and become thinner towards the south and east, as also do the other beds, so that it is not always possible to recognise them on the coast sections. The following is the section at Hawsker Bottoms.

Section of the Spinatus-*beds, Hawsker Bottoms.*

No.	Petrology.	Thickness. Ft.	In.	Organic Remains.
	Soft blue shale of the *annulatus* series.			
1	Ironstone doggers -	0	3	*Pecten æquivalvis* (large), *Bel. breviformis.*
2	Soft sandy shale - -	1	2	
3	Finely laminated sulphurous shale.	0	4	
4	Soft sandy shale - -	0	10	
5	Red ironstone doggers, probably equivalent to Cleveland main seam.	0	3	*Am. spinatus, A. ferrugineus, Pecten æquivalvis, Pleuromya rostrata, Modiola scalprum, Monotis inæquivalvis, M. calva, Inoceramus substriata, Unicardium subglobosum, Rhynchonella, Leda graphica, L. galathea, Dentalium elongatum.*

No.	Petrology.	Thickness.	Organic Remains.
		Ft. In.	
6	Calciferous sandstone with much ferruginous matter.	1 6	
7	Solid hard sandy shale -	5 3	*Am. spinatus*, *Leda galathea*, fucoid markings ?
8	Variable red doggers -	0 6	*Pecten æquivalvis*, *Pholodomya ambigua*, *Monotis inæquivalvis*, and many small shells, Gasteropods, *Astarte*, *Limea*, &c.
9	Strong solid shale -	6 0	
10	Red doggers - -	0 4	*Pecten æquivalvis.*
11	Shale - - -	0 8	
12	Irregular knobbly doggers	0 4	*Pecten æquivalvis*, *Bel. breviformis*, *Limea acuticosta.*
13	Hard blue shales with scattered doggers.	4 4	
14	Irregular doggers -	0 4	*Am. spinatus*, *Am. solitarius*, *Am. ferrugineus*, *Am. reticularis*, *Bel. breviformis*, *Cryptænia expansa*, *Chemnitzia Blainvillei*, *Turbo cyclostoma*, *Pleuromya costata*, *Modiola numismalis*, *Leda galathea*, *L. subovalis*, *L. graphica*, *Cucullæa liasina*, *Plicatula spinosa*, *Inoceramus substriatus*, *Astarte striato-sulcata*, *Protocardium truncatum*, *Myoconcha decorata*, *Limea acuticosta*, *Monotis inæquivalvis*, *Pecten æquivalvis*, *Arcomya arcacea*. *Rhynchonella lineata.*
15	Friable shales with irregular doggers.	6 0	
16	Knobbly doggers -	0 5	*Pecten æquivalvis*, *Bel. breviformis*, *Gryphæa cymbium*, *Pholadomya ambigua.*
17	Rough friable shales -	5 3	
	Double dogger of the *margaritatus* series.*	—	
	Total - - -	33 9	

* As noticed on page 75 we should be inclined to include nearly 20 feet more of beds in the zone of *Am. spinatus.*

The next place that the *spinatus*-beds come to the surface is at Kettleness, where Messrs. Tate and Blake give the following section:—

Section of Spinatus-*beds, Kettleness.*

No.	Petrology.	Thickness. Ft.	In.	Organic Remains.
	"Grey shales."			
1	Sandy shale - -	1	9	
2	Small argillo-arenaceo-calcareous doggers.	1	8	*Pleuromya costata, Pecten æquivalvis.*
3	Sandy marls - -			
4	Black laminated shale -	0	6	
5	Sandy marl - -	1	1	*Am. spinatus, Rhynchonella tetrahedra.*
6	Sandy argillaceous limestone doggers, with an irregular surface.	0	6	*Am. spinatus, Unicardium subglobosum, Pleuromya costata, Rhynchonella tetrahedra, Pentacrinus amalthei.*
7	Hard sandy shale -	4	8	
8	Dogger-band to 5 inches -			
9	Hard sandy shale -			
10	Shale with scattered fossiliferous doggers, gypsum partially enveloping the same; some specimens of Ammonites in blende and iron pyrites.	2	0	*Am. spinatus, Am. ferrugineus, Chemnitzia Blainvillei, Turbo cyclostoma, Dentalium elongatum, Arcomya arcacea, Inoceramus substriatus, Leda graphica, L. subovalis, L. galathea, Macrodon Buckmani, Astarte striato-sulcata.*
11	Dogger band, 3 inches -			
12	Shale - - -	[1	6]	*Am. spinatus, Pecten æquivalvis.*
13	Top block of main seam of ironstone, a subcrystalline calcareous ironstone.	1	9	*Am. spinatus*, and other fossils of the section.
14	Hard shale - -	2	4	*Am. spinatus, Pecten æquivalvis, Bel. microstylus, B. clavatus, B. breviformis*, &c.
15	Bottom block of main seam of ironstone, a ferro-argillaceous ironstone.	1	6	*Ostrea submargaritacea.*
16	Hard shale - -	1	7	

Below this there are about 20 feet of ferruginous shale and bands of impure ironstones, many of which pass so gradually into one another that it is very difficult to separate out the different beds.* It is probable that the whole of the beds seen here belong to this zone, and that the *margaritatus*-beds are not represented at all in the strata seen above low-water mark.

The full thickness of the beds here exposed is about 40 feet.

On the opposite side of Runswick Bay the ironstone beds were met with in mining operations, but they do not come above the

* *See* page 100.

surface till we reach Brackenberry Wyke near Staithes, where the section is :--

Section of the Spinatus-*beds, Staithes.*

No.	Petrology.	Thickness. Ft.	In.	Organic Remains.
	"Grey shales."			
1	Black micaceous marly shales with a row of limestone balls.	1	5	*Pleuromya costata, Pecten æquivalvis, Pholadomya costata, Pinna spathulata.*
2	Laminated shales -	0	9	
3	Friable sandy shales, with limestone nodules at the bottom.	1	6	*Pleuromya costata, Rhynchonella lineata.*
4	Greyish brown marly sandstone.	0	6	*Am. spinatus, Pleuromya costata, Pholadomya costata, Unicardium subglobosum, Pecten æquivalvis, Modiola scalprum, Limea acuticosta, Protocardium truncatum, Rhynchonella tetrahedra.*
5	Sandy marl - -	3	6	
6	Top block of main seam; surface covered with small branching fucoids.	3	0	*Am. spinatus, Pecten æquivalvis, P. lunularis, P. substriatus, Unicardium janthe, Pleuromya rostrata, Rhynchonella lineata.*
7	Shale - - -	1	0	
8	Bottom block of main seam; surface covered with long tortuous fucoids.	2	2	
9	Shale - - -	0	8	*Pholadomya ambigua, Plicatula spinosa, Ostrea submargaritacea, Rhynchonella lineata.*
10	Ironstone - -	0	4	
11	Shale - - -	0	6	
12	Ironstone - -	0	4	
13	Shale - - -	0	6	
14	Ironstone - -	0	7	*Belemnites breviformis.*
15	Shale - - -	0	10	*B. breviformis, Pecten æquivalvis, Monotis cygnipes.*
16	Ironstone - -	0	6	*Monotis cygnipes, Arcomya arcacea, Ostrea submargaritacea, Rhynchonella tetrahedra.*
17	Shale with a ferruginous parting, or narrow ironstone band.	0	8	*Pecten æquivalvis, P. lunularis, Monotis cygnipes, Ostrea submargaritacea, Plicatula spinosa, Rhynchonella calcicosta, Terebratula punctata.*
18	Ironstone - -	0	5	*Lima Hermanni, Rhynchonella tetrahedra.*
19	Marly shale - -	2	6	*Pecten æquivalvis.*
	Zone of *Am. margaritatus.*			
	Total - -	21	8	

In the above section the divisions 6, 7, and 8 constitute the Main Seam, while the thin ironstones 10 to 18 inclusive probably represent the Pecten Seam, but the intervening shale No. 9 is thicker than here given. No. 20 is the Two-Foot Seam as

previously stated, and there are 27 ft. 7 in. more of ironstones and shales before the Avicula or Bottom Seam is reached, thus making the total of this series 49 ft. 3 in.*

From this point the ironstone beds turn inland for a space, but appear again in the precipitous cliffs of Boulby. But neither here nor at Huntcliff do the sections call for particular remark. The more minute details of the outcrop are given in the general account of the Ironstone Series.†

Fossils from the Zone of Am. spinatus.

PLANTÆ.

Chordophyllites cicatricosus, *Tate.*
Nulliporites furcillatus, *Tate.*

ECHINODERMATA.

Cidaris amalthei, *Quenst.*
Rhabdocidaris, sp.

ANNELIDA.

Ditrupa capitata, *Phil.*
—— circinata, *Tate.*
Ditrupa quinquesulcata, *Münster.*
Serpula limax, *Goldf.*

BRACHIOPODA.

Lingula sacculus, *Chap. & Dew.*
Rhynchonella capitulata, *Tate.*
—— calcicosta, *Quenst.*
—— fodinalis, *Tate.*
—— lineata, *Y. & B.*
—— oxynoti, *Quenst.*
—— tetrahedra, *Sow.*
Spiriferina signiensis?, *Buvig.*
—— Walcotti, *Sow.*
Terebratula punctata, *Sow.*
Waldheimia florella, *d'Orb.*
—— —— var. pyriformis, *Dav.*
—— perforata, *Piette.*

LAMELLIBRANCHIATA.

Anomia numismalis, *Quenst.*
Avicula calva, *Schlönb.*
—— cygnipes, *Y. & B.*
—— inæquivalvis, *Sow.*
—— papyria, *Quenst.*
—— substriata, *Ziet.*
Hinnites tumidus, *Ziet.*
Inoceramus substriatus, *Münster.*
Lima eucharis, *d'Orb.*
—— Hermanni, *Voltz.*
Limea acuticosta, *Münster.*
—— juliana, *Dum.*
Ostrea sportella, *Dum.*
—— submargaritacea, *Brauns.*
Pecten æquivalvis, *Sow.*
—— lunularis, *Röm.*
—— substriatus, *Röm.*
—— verticillus?, *Stoliczka.*
Perna lugdunensis, *Dum.*
Pinna spathulata, *Tate.*
Plicatula calva, *Desl.*
—— spinosa?, *Sow.*
Arcomya arcacea, *Seebach.*
—— concinna, *Tate.*
—— longa, *Buvig.*
Astarte rugata, *Quenst.*
—— striato sulcata, *Röm.*
Cardinia crassissima, *Sow.*
—— lævis, *Y. & B.*
Cardita multicostata, *Phil.*
Cardium truncatum, *Sow.*
Ceromya bombax, *Quenst.*
Ceromya petricosa, *Simp.*
—— sublævis, *Tate.*
Cypricardia cucullata, *Münster.*
Goniomya hybrida, *Münster.*
Gresslya intermedia, *Simp.*
Hippopodium gigas, *Tate.*
—— ponderosum, *Sow.*
Leda galathea, *d'Orb.*
—— graphica, *Tate.*
—— subovalis, *Goldf.*
Lucina pumila, *Münster.*
Macrodon Buckmani, *Richardson.*
—— clevelandicus, *Tate.*
—— intermedius, *Simp.*
Modiola numismalis, *Oppel.*
—— scalprum, *Sow.*
——Thiollierei, *Dum.*
Myoconcha decorata, *Münster.*
Mytilus aviothensis, *Buvig.*
Nucula cordata, *Goldf.*
Pholadomya ambigua, *Sow.*
—— lunata, *Simp.*
—— Simpsoni, *Tate.*
Pleuromya costata, *Y. & B.*
Tancredia broliensis?, *Buvig.*
—— longiscata, *Buvig.*
—— lucida, *Terquem.*
Tellina fabalis, *Simp.*
—— lingonensis, *Dum.*
Thracia Grotiani, *Brauns.*
Trigonia lingonensis, *Dum.*
Unicardium subglobosum, *Tate.*

* Page 76.

† Page 98 *et seq.*

SCAPHOPODA.

Dentalium elongatum, *Münster.*

GASTEROPODA.

Actæonina chrysalis, *Tate.*
—— ilminsterensis, *Moore.*
Cerithium acriculum, *Tate.*
—— liassicum, *Moore.*
Chemnitzia Blainvillei, *Münster.*
—— nuda, *Münster.*
—— semitecta, *Tate.*
Cryptænia consobrina, *Tate.*
—— expansa, *Sow.*
Eucyclus cingendus, *Tate.*
—— conspersus, *Tate.*
Eucyclus nireus, *d'Orb.*
—— undulatus, *Phil.*
Nerita alternans, *Tate.*
Pleurotomaria helicinoides, *Röm.*
—— rustica, *Desl.*
—— undosa, *Desl.*
Turbo aciculus, *Stoliczka.*
—— cyclostoma, *Bens.*
—— latilabrus, *Stoliczka.*
—— lineatus, *Moore.*

CEPHALOPODA.

Ammonites ferrugineus, *Simp.*
—— Holandrei, *d'Orb.*
—— lenticularis, *Y. & B.*
—— margaritatus, *Mont.*
—— solitarius, *Simp.*
—— spinatus, *Brug.*
Belemnites acuminatus, *Simp.*
—— apicicurvatus, *Blain.*
—— breviformis, *Voltz.*
Belemnites clavatus, *Blain.*
—— compressus, *Stahl.*
—— cylindricus, *Simp.*
—— longiformis, *Blake.*
—— microstylus, *Phil.*
—— Milleri, *Phil.*
—— paxillosus, *Schlot.*
—— rudis, *Phil.*
—— vulgaris, *Y. & B.*

REPTILIA.

Plesiosaurus, sp.

MIDDLE LIAS.

General Account.

The Middle Lias is divided into two portions, the Sandy Series and the Ironstone Series; these when well developed, as in the northern part of the area, are capable of being mapped separately, and therefore in the following pages we will take them singly as far as practicable.

As we mentioned previously, the limits of these divisions do not coincide with those formed by the palæontological zones; for which reason we repeat the coast sections, giving the measurements made by Mr. Barrow during the survey of the district.

THE SANDY SERIES.*

The Sandy Series which includes the upper part of the zone of *Am. capricornus* and the lower part of that of *Am. margaritatus* consists of alternations of hard sandy shales and thin micaceous, calcareous, and ferruginous sandstone, the whole marked by the extreme abundance, along certain lines, of *Cardium truncatum, Gryphæa cymbium,* var. *depressa,* &c. Of these *Cardium truncatum* is very abundant, especially in the upper part, while lower down *Gryphæa cymbium* predominates, and is accompanied by *Avicula inæquivalvis;* calcareous bands near the base, often consisting entirely of these two species. In one particular bed *Dentalium giganteum* occurs in considerable numbers, while *Belemnites* and *Pecten* are tolerably abundant throughout.

* The following stratigraphical details are mainly taken from the information given by Messrs. Reid and Barrow in the Geological Survey Memoirs descriptive of the Quarter-Sheets 95 N.W., 96 N.W., 96 S.W., 96 N.E., 104 S.W., 104 S.E.

The sandstone itself has a bluish tinge before exposure to the atmosphere; but as the iron and lime are slowly dissolved out, the stone often changes to a soft, close-grained, micaceous, flaggy sandstone; the flaggy structure being partly occasioned by the lines of shells. Upon splitting the stone open the faces are mostly found covered by casts of shells, principally *Cardium, Gryphæa, Pecten*, and *Avicula*. Where the sea has acted upon blocks of this sandstone, the salt water seems to rather harden the lime and iron; and thus the fallen block on the beach may be split up along the lines of fossils, and excellent small flags be obtained perfectly covered with *Pecten, Gryphæa*, &c., stained a rich red from the iron they contain.

These beds were originally called the "Marlstone series" by Prof. Phillips and others; but as this name was used to include both the whole of the Middle Lias, and has also been applied to either division separately, it has not much definite signification, and has now been abandoned for the Yorkshire rock.

The Sandy Series is first seen between the faults at Peak Steel, from whence it is thrown up by the large fault, on the west side of which the cliff is capped by the sandstones and sandy shale of this series. The pathway down to the great slip under the cliff at Peak is almost on the line of Fault, and to the left the sandstones are seen, containing the following species: *Am. margaritatus, Hippopodium ponderosum, Cardium truncatum*, and *Gryphæa cymbium*, in abundance, *Dentalium*, &c. But as they are almost all casts this is not a good place for collecting. From this point the sandy beds make a well-marked terrace round the south-east side of the great amphitheatre of the Bay, and sink under the Boulder Clay beneath the Brow Alum Quarry.

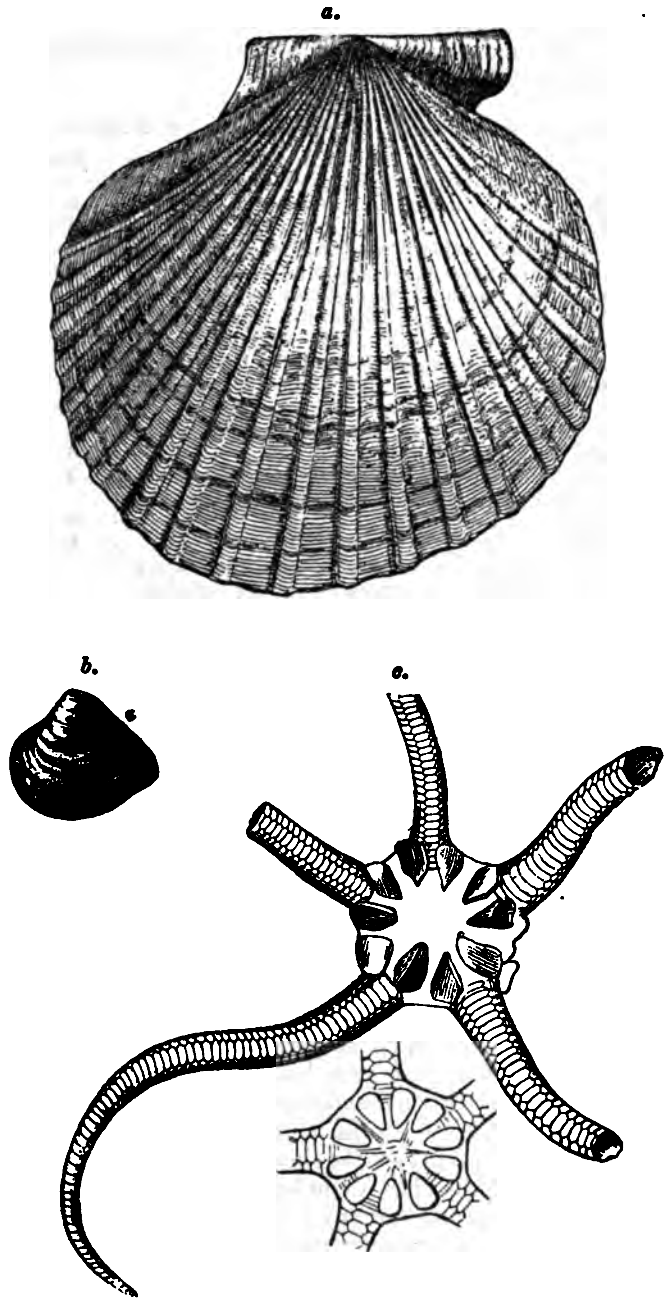
It is impossible not to regret this covering of Boulder Clay; as nothing is more striking than the extreme symmetry of the south-east end of the Bay, where the beds crop out to the surface in a succession of curving terraces; whilst the north end, from its thick covering of Boulder clay, seems almost shapeless. In this natural exposure of the beds several small sections may be seen, principally in the narrow but deep ditches that drain the fields; only in Tan Beck, however, is there a section of the whole of these sandy beds. The sandstones are cut through in the road at Susanna Hill; but westward of this we have no sections till we reach Butcher Close Wood, which is situated on the sides of the south branch of Mill Beck. Here the base of the Middle Lias is exposed; the section being as follows:—

	FEET.
Shale, hard and sandy - - - - - -	5
Sandstone, laminated, and full of casts of *Avicula inæquivalvis, Gryphæa cymbium*, and *Am. capricornus* - - -	3
Hardy sandy shale almost white; dark shales with small iron-stone doggers, and containing *Am. capricornus*, for some distance down the stream - - - - - -	

Above this section the stream flows in Boulder Clay. In Mill Beck, about 100 yards west of the new bridge, hard sandy shales with *Rhynchonella* and *Pecten lunularis* crop out, and from their lithological character we suppose them to be part of this series.

FIG. 4.

Middle Lias Fossils.



a, Pecten æquivalvis, *Sow.* (after Goldfuss) [illegible]; *b*, Cardium truncatum, *Sow.* (Original) [illegible]; *c*, Ophioderma Milleri, *Phil.* (after Wright) [illegible].

There are no more exposures in this district until we again reach the cliff, about 300 yards north of Bay Town; and from this point the beds fall gradually, till they finally reach the sea-level at Dobson's Nab.*

In these cliffs and along the shore we have the following detailed section of these beds:—

Section of the Sandy Series at Hawsker Bottoms.

	Ft.	In.
Thin calcareous sandy band, forms the top of Dobson's Nab: layers of *Cardium truncatum*, &c.	0	10
Hardy sandy shale	4	0
Calcareous sandy shale: *Dentalium giganteum*, *Gryphæa*, *Cardium truncatum*, &c. abundant	5	0
†Close-grained sandstone, ferruginous and calcareous, containing four distinct bands of fossils: *Gryphæa*, *Cardium*, &c.	3	0
Hard sandy shale with *Am. margaritatus*, *Pecten*, *Belemnites*, &c. in bands	2	4
Dogger band	0	4
Hard sandy shale with an eight-inch fossiliferous nodular band at the base	3	0
Hard shale, darker than above: *Pecten*, *Belemnites*, &c.	5	4
Calcareous and ferruginous dogger band: *Am. capricornus*	0	6
Hard shale	0	6
‡Very hard ferruginous sandstone, containing layers of fossils: *Dentalium giganteum* being very abundant in the uppermost; *Am. capricornus*, *Bel. clavatus*, *Gryphæa cymbium*, &c. abundant; *Cardium truncatum* being found occasionally	4	6
Sandy shale with dogger band at the base	4	10
Sandy shale with scattered fossiliferous doggers and fossil wood	10	0
Dogger band with fossils	0	3
Shale with band of septariated nodules at the base	1	0
Shale with thin lines of *Gryphæa*, &c.	4	9
Shale with dogger band at the base, almost composed of shells	2	8
Thin sandy laminæ, passing into a calcareous band composed of *Gryphæa cymbium* and *Avicula inæquivalvis*, accompanied by *Am. capricornus*, *Eucyclus undulatus* *Rhynchonella calcicosta*, *Belemnites*, &c.	1	6
Total	54	4§

North of this these beds do not appear again till we reach Staithes, just east of which they rise from the sea, the upper part forming the long flat scar known as Penny Stile. Here *Am. margaritatus*, *Cardium truncatum*, and many small fossils may be found. The strata rise to the west, and the upper beds can be carefully measured as far as the beach in front of the village, where the small beck has denuded away part of the series. There is, however, no trace of any fault here, as has so often been

* Close to Castle Chamber on the One-Inch Map.

† Forms the roof of Castle Chamber, a small hollow in the cliff at high-water mark.

‡ Forms the floor of Castle Chamber.

§ When measured with a rope the thickness was found to be about 60 feet; but as the cliff was not quite perpendicular 54 feet is probably nearer the truth.

asserted; a fact that can be conclusively proved at low-spring-tides.

The rest of the series can be measured and carefully examined in Staithes Nab, the whole giving the following section.

Section of Sandy Series at Staithes.

	Ft.	In.
Finely laminated, calcareous sandstone, *Am. margaritatus*, *Cardium truncatum*, &c.	0	10
Hard sandy shale, slightly calcareous	5	0
Finely laminated calcareous sandstone	1	0
Hard sandy shale	4	6
Sandstone, fissile, with bands of *Cardium truncatum*, *Am. margaritatus*, *Avicula cygnipes*, *Dentalium giganteum*	13	0
Sandy shale	4	6
Hard laminated sandstone, layer of *Gryphæa depressa*	1	2
Sandy shale	1	3
Hard sandstone, shelly band above and below	1	3
Shale with sandy ferruginous nodules *Am. capricornus*	5	3
Hard sandstone with several shell bands	4	3
Sandy shale	2	0
Ferruginous and micaceous sandstone	0	10
Hard sandstone; *Am. capricornus*, *Gryphæa depressa*, *Avicula inæquivalvis*	2	0
Hard sandy shale	7	0
Sandstone	2	0
Shale	1	6
Flaggy sandstone	3	0
Harder sandstone with three oyster bands	3	0
Sandstone softer towards the lower part, with thick bed of *Gryphæa depressa** at base	5	6
Softer shales of Lower Lias.		
Total	68	10

Or nearly 70 feet.

These beds may be followed up Staithes Beck, past Dalehouse, and up Rousby and Easington Becks, sections being frequent and clear; from which most of the characteristic fossils may be obtained. The greater portion of the Sandy Series forms the bearing rock of the cliff from Staithes nearly to Boulby Alum Works. Though clearly seen as far as Hummersea they are quite inaccessible till the latter place is passed, when the massive bed containing the bands of *Gryphæa* (*Ostrea*) comes down to about high-water mark, and continues approximately in that position as far as Skinningrove. About here these beds are fairly accessible for fossil collecting. Beyond Skinningrove a nearly complete section is seen in Catterstу Beck, after which clay covers the entire outcrop as far as Huntcliff Mine; where, as it only re-appears in the cliff-face, it is quite inaccessible. Keeping this latter position as far as the most northerly part of Huntcliff, the Sandy Series again passes inland under Drift, two sections, however, being shown by the cutting through the clay in Salt-

* This bed yields many fossils; the chief are *Am. capricornus*, *Gryphæa depressa*, *Avicula inæquivalvis*, and a small variety of *Cardium truncatum*.

burn Gill; the first of these is near the base; the second is the exact top of the series.*

There is an isolated outcrop of these sandstones with *Cardium truncatum* at the seaward end of the Redcar reefs, but it is very inaccessible and fossils can only be extracted with difficulty. Indeed, its only point of interest is the fact of its occurrence in this position, as it is strongly suggestive of some great fault out to sea cutting off all the Liassic beds, and bringing up the New Red Series.

In Skelton Beck the first section is exactly at the south boundary of Saltburn Gardens, where the middle of the series is seen. Under Rushpool, slightly higher beds crop out, and from this point as far as Skelton Mill the bed and sides of the stream are composed of the highest part of the Sandy Series. Throughout the whole distance fossils may be collected; and near Marske Mill in particular a considerable variety of species are to be found, such as *Am. margaritatus, Discohelix aratus, Dentalium elongatum, Chemnitzia Blainvillei, Avicula inæquivalvis, Cardium truncatum, Pecten lunularis,* and several others.†

On the three other sides of Hob Hill, the country is entirely covered by Drift, and the outcrop can be only approximately fixed, the same condition of things prevailing round Upleatham Hill. In the higher part of Yearby Wood, called the Folly, several openings have been made in thin sandstones containing *Cardium truncatum,* and from this point westward the Sandy Series is practically exposed in every small stream overlooking Wilton Castle and the surrounding district. The road over the escarpment to Wilton gives the following section:—

	Ft.	In.
Shales, ferruginous and sandy	—	
Sandstone, with shell bands	2	6
Rubbly sandstone, breaks up small	6	3
Sandstone, very hard, finely laminated	1	8
Sandstone, soft	9	0
Sandstone, hard, laminated, shelly in middle	1	0
Sandy shale	6	0
Hard sandstone, marly bands, base not seen, about	30	0

This shows only the upper part clearly; but it is at once apparent that the whole series is far thicker than at Staithes, and still more so than in the district just east of Whitby; there is besides a distinctly more arenaceous character in the beds here.

A few yards west in Waterfall Gill the following section was measured:—

	Ft.	In.
Soft rubbly sandstone, *Avicula cygnipes, Cardium,* &c.	5	0
Harder sandstone, ferruginous nodules	6	0
Sandstone with ferruginous bands of *Cardium truncatum*	6	0
Soft rubbly flaggy sandstone	25	0
Hard marly beds	10	0

* This last section is figured by Messrs. Tate and Blake (Yorkshire Lias, p. 111), but the amount of disturbance is really very slight, and similar to what constantly occurs at the junction of a thick bank of Boulder Clay with the rocks beneath; it may be glacial action, but we believe it to be due solely to the sliding of the heavy clay bank above.

† See The Yorkshire Lias, pp. 134, 5.

Small exposures of these beds occur at intervals about the Eston Mines. The great level-drift into the hill commences just at their base and cuts right through them, each stratum being penetrated in turn, as it is brought down by the dip, which is "into the hill." To the south, near Upsall Mill, is a small patch of the Sandy Series, brought up into the position shown in the map by the great Upsall Fault.

At the south end of Scugdale Slack, the deep hollow running up into Eston Hill, shales with thin ironstone-bands are seen, below which come thin flaggy sandstones evidently belonging to the Middle Lias. These sandstones make a good feature east and west, by which the outcrop is mapped; their position still further east is proved by the exposure of Lower Lias shale in the adit north of Howl Beck Mill. The outcrop on the north side of the fault can only be approximately calculated, as the sole evidence is the small opening in the sandstone beds cropping out just under the road in Tocketts Plantation, north-east of Guisbrough. About Waterfall Wood the position of the Sandy Series is uncertain on account of the thick covering of Drift, but the railway cutting near Foxdale shows the lowest bands of sandstone with *Am. capricornus*, *Avicula inæquivalvis*, and the characteristic beds of *Gryphæa cymbium*, var. *depressa*.

In Belman Bank the road passes over an almost complete section of the Sandy Series, from which most of the common fossils can be obtained, though principally in casts. Further west, openings have been made at intervals as far as the old Hutton Mines. Here the incline and the various old paths give several clear sections of the upper beds, one of which is as follows:—

	Ft.	In.
Finely laminated, ferruginous sandstone	3	6
Soft sandstone and sandy shale with *Cardium truncatum*	6	6
Hard lenticular sandstone in concretions	1	0
Flaggy sandstone and sandy shale	7	6
Hard thin micaceous sandstone	4	6
Sandy shales and thin sandstones, many fossils	6	0

Below this, the rubbish from the hill-sides has obscured the section, which throughout contains *Cardium truncatum* in great numbers.

The greater part of the long narrow hill to the west of Hutton Hall is composed of these sandstones and shales, which continu to form the steepest part of the bold escarpment flanking the low ground of the Vale of Cleveland. About Roseberry Topping and the great Whinstone Ridge, exposures are numerous. There is an outlier of the Sandy Series close against the whinstone quarries due south of Roseberry, but the main outcrop, north and east of this, is covered by clay. In the road from Ayton Cottage to Captain Cook's monument, the ruts show sandstone with *Cardium truncatum*, the outcrop being once more free of Drift as far as Burrow Greens. Just beyond this a small pre-glacial valley divides the outlier near Easby from the main mass of the series,

which continues on the east side of the Drift-filled hollow, following round the great Oolitic outlier on which the monument stands. Emerging from its Drift-cover, along the west bank of the Leven in Kildale, the Sandy Series gradually gets nearer the stream, till its base enters the water at Old Meggison, where it forms the top of the waterfall. The upper beds continue in the bank along which the new road has been cut, sections in consequence being numerous. This is an extremely pretty district, and worth a visit apart from the favourable opportunities for examining sections. Further east, the deeper parts of the dale are completely filled with gravel, and the Sandy Series is lost sight of. South of this under Battersby Crags great masses of gravel flank the main escarpment; the spur of rock in Coleson Banks being the first clear section of these beds, where a small opening, evidently near the base of the Middle Lias, shows thin flags with *Gryphæa cymbium*. Where clear of Drift the Sandy Series forms a prominent terrace in the hill side, by which it may be traced round the great quadrangular escarpment; the detritus is, however, usually too thick to allow the beds *in situ* to show through, and it is only in large landslips that they are actually seen. The finest of these occurs at Blue Bell Trough, and gives the following section:—

Section of the Sandy Series at Blue Bell Trough, Burton Head.

	Ft.	In.
Calcareous and ferruginous sandstone with shaly partings, containing *Cardium truncatum*, &c. in great numbers	3	6
Hard, sandy shale, and thin sandstone	5	0
Hard sandstone, ripple marked	4	0
Softer ferruginous sandy shale	7	0
Hard micaceous flaggy sandstone	3	6
Sandy shale	4	6
Hard concretionary sandstone, crowded with *Cardium truncatum*, *Gryphæa cymbium*, *Pecten sublævis*, *Pecten lunularis*, *Myacites*, sp., and occasionally *Ammonites margaritatus*	10	6
Shale	3	6
Sandstone (small specimens of *Cardium truncatum*)	1	0
Sandstone and shale bands alternating, with *Gryphæa* beds at base	25	0
Total	67	6

Passing round into Bilsdale, the west side of the high-road shows a cutting in the upper sandstone beds of this series; and exposures are numerous in the neighbourhood, almost every small stream flowing down the sides of the dale showing some part of the Sandy Series.

Just south of Chop Gate a bridle-road goes up the hill on to the moor, where the rain has washed these beds bare so that they can be clearly examined though not measured. Good exposures also occur in Stingamire Gill on the west side of the dale, and in Kyloe Gill, just north of High Crosset, on the east; beyond which the Sandy Series dips beneath the bottom of the valley.

West of Bilsdale the Sandy Series is well exposed in Tom Gill Scar in Carlton Bank, and consists of sandstones and thin shales with shelly bands for the first 35 feet; below which is about 40 feet of sandy shale, still rather hard, with the usual characteristic bands of *Gryphæa cymbium* at the base. As a rule, the great scars of Lower Lias are capped by these basement beds of the Middle Lias, so that along the face of Dromonby Bank sections are fairly numerous and clear.

In the eastern of the two upper branches of Raisdale these beds form two flat topped terraces, the little stream cutting a narrow gorge between and exposing a small part of the Lower Lias. The junction of the latter with the Sandy Series is well marked in the stream at the lower end of the dale, the *Gryphæa* bands being strongly developed.

Only the upper beds crop out in the western dale, forming as usual a flattish area round the stream in which the calcareous flags are seen at intervals, especially about Broomflat.

In the main valley of Raisdale the Sandy Series is suddenly faulted up near High Crosslets, from which place these beds trend south-east and east, the whole of the beds being shown in Hartman Gill. On the north side of the dale a considerable part of the series is faulted out, but small outcrops are visible about West Cote and Cock Flat.

Returning northwards the flaggy beds are well seen at the north end of Whorl Hill; and on the east side of the great fault the *Cardium truncatum* sandstones lie right against the Upper Lias. Nearer Swainby Mines the ground is entirely covered by Drift, and for some distance along the north side of Scugdale the Sandy Series is faulted out; the first exposure being in a small stream below Scugdale Hall. In the main stream there is only one section of thin sandstone, the superficial deposits completely covering the bottom of this dale throughout its entire length; but to the south the beds are at a somewhat higher level and rise clear of the Drift. The position of the series is in consequence marked by the well-known terrace, and good sections are seen about Holiday House. To the west of Harfa Bank the outcrop is thrown up by a considerable fault, and beyond this is clear of Drift for a great distance. Still, in passing through Limekiln Bank Woods the downwash is sufficiently thick to obscure the rocks till the road up to Scarth Nick is reached, where there is a clear section of the whole series.

The large fault at Scarth Nick throws these beds down below the level of the Drift, and they are completely obscured till the outcrop is thrown up again by another fault round the north-west corner of the escarpment. Throughout the Arncliffe Woods small fragments of the characteristic sandstones may be picked up, and the actual junction of the Middle and Lower Lias is well seen below Lady's Chapel. There are several exposures in Far Clack Wood, Clack Wood, and the road between them, after which the Drift again creeps up the hill-side and obscures the strata. In Oak Dale the little stream cuts through the Sandy Series, the

following being a brief summary of the section. At the top comes the usual alternation of thin sandstones and sandy shales, below which is the typical sandstone, some 12 feet thick, crowded with fossils. The chief of these are *Cardium truncatum*, *Gryphæa cymbium*, *Dentalium giganteum*, and *Pecten æquivalvis*. Some 15 feet of sandy shale separate the last bed from a shaly sandstone, 10 feet thick, containing the usual *Gryphæa* beds near its base.

At the weir above Osmotherley Flour Mill thin lenticular sandstones, with alternating bands of sandy shale, pass completely up into the Ironstone Series; so that the lithological boundary between the two divisions is ceasing to exist, the whole Middle Lias becoming more arenaceous.

About Thimbleby there are only a few small exposures; but south of Nun House, at a small hollow in the hillside, the following section is seen.

Section at Nun House, near Over Silton.

		Ft.	In.
Ironstone Series,	Soft grey shale	5	0
	Ironstone, shelly, oolitic, AVICULA SEAM	1	1
	Ferruginous shale with nodules	6	0
Sandy Series 36 ft. 0 in.	Lenticular sandstone "dogger," resting on sandstone with thin shale partings	18	0
	Shaly sandstone	5	0
	Hard flaggy sandstone, with *Cardium truncatum*	1	0
	Soft rubbly sandstone, with *Gryphæa* bands at base	12	0

This is probably an under estimate, and 40 feet would be more exact; but, considering that on the coast the beds in one place attain a thickness of nearly 100 feet, it is evident that they are slowly dying away in a south-westerly direction.

There is, moreover, only six feet of shales below the Avicula Seam in this section, whereas further N.E. there is as much as 25 feet.

For some little distance to the south the outcrop of the Sandy Series is clear, and exposures numerous; but after rounding the corner of the escarpment at Over Silton the Drift creeps up the hill and hides these beds for several miles. In the outlying hill of Upsall the *Cardium truncatum* sandstones may be seen in the road below Upsall Castle, after which no exposures occur till Hole Wood south of Feliskirk Village is reached, where fragments of sandstone and sandy shale are seen, the beds making a well-marked feature in the hill face.

To the south and east of this no rock is visible *in situ* for a considerable distance, and the outcrop has to be inferred from the relative position of the Upper and Lower Lias. The beds also are much thinner, and therefore it is preferable in this region to take the whole of the Middle Lias together.* For this reason, before proceeding further with the main outcrop, it will be better to describe the Sandy Series of the interior dales, and the Ironstone Series of the whole country to the north and east, which practically forms one area, distinct from the feeble representative of these beds to the south.

* Continued on page 118.

Inliers of the Sandy Series.

In Eskdale the Sandy Series has a thickness of about 60 feet, and consists of the following three divisions:—

(*a.*) Upper part, consisting of two hard thin bands, with about four feet of shale beneath each.
(*b.*) Main mass of sandstone, with many bands of *Cardium*, &c.
(*c.*) Thick bed of hard sandy shale, with thin beds of sandstone in it.

The two hard thin bands in the upper part are very persistent, and form a convenient datum line for correlating the different seams of ironstone in Cleveland.

The most easterly exposures are near Sleights, where the whole series may be seen on the sides of the river, although the sections are obscured by vegetation. Near Woodlands a small stream cuts through the upper part of the series, and exposes, at the base of a small fall on the side of the Esk, hard sandy shales, with *Avicula*, *Gryphæa*, and occasionally *Am. capricornus*; showing that this is near the base of the Middle Lias. On the opposite side of the river, a little further up, immediately under the railway, the lowest band of sandstone, with the characteristic "oyster beds," consisting of *Gryphæa cymbium* and *Avicula inæquivalvis*, may be seen rising from the river, dipping 3° slightly E. of N. The base of the series is seen again half a mile to the S.W. in the Beck below Eskdale Gate; but this section is very small, and entirely surrounded by Boulder Clay. A little further west the hard sandstone beds cap the great scar (Blue Scar) on the south side of the Esk. A complete section is here shown, but it is quite inaccessible.

About Grosmont, on the south side of the Esk, several small sections are seen, but it is difficult to obtain many fossils from these exposures. On the north side of the river the Boulder Clay completely obscures these beds, although they were proved in a boring at the North Mine.

In Glaisdale though the Sandy Series undoubtedly occurs it is entirely hidden by Drift, and has therefore not been separated from the Ironstone Series.

Both Great and Little Fryup show several small sections of these shales, the best being in the gill near Fryup Hall, and in Slidney Dike, a quarter of a mile from Wood Head. In Little Fryup the shales are only seen in the beck south of Stone Beck Gate, and in the road a furlong east of the same place. None of these sections allow of detailed measurements.

The sections in Danby Dale are numerous though small. The best are in the immediate neighbourhood of the church, *Cardium truncatum* being found in abundance in the churchyard. Other exposures can be seen in the bridle-road through Church Wood, and also in various parts of the gill below the wood. Road

sections occur in Bur-tree Lane, near Gate House, and at Midge Holes, and there are also small exposures in the two gills north-east of Nook House.

In Westerdale there are probably better sections of the Sandy Series than in any other of the inliers, but nowhere can the beds be measured. Commencing with the eastern branch of the dale, exposures of sandy shale can be examined a short distance south of Wyett Bridge, and also in the gill near Petch House. The higher part of the same gill shows thin cherty flags, probably belonging to the Sandy Series, but of a character unusual in the Lias. At the north end of Old Mill Wood there is a small section of flaggy sandstone, and similar beds re-appear in the gills east of Tower Bridge. Further south, at Cock Bannock and near Round Hill, sandy shales with cherty ironstone doggers are seen, probably forming the top of the Sandy Series.

Some of the best sections in Westerdale are seen in Bagdale Dike, near Westerdale Hall, where sandy shales and flaggy sandstone with *Cardium truncatum* are exposed. The same beds re-appear in Flats Gill, near the Grange. Though the shales are again seen in Stock Dale there is a good deal of disturbance in the whole of the western branch of Westerdale. The only other clear section occurs due east of Robin Leys House, where, close to the beck, a scar shows :—

	Ft.	In.
Flaggy sandstone.		
Shales - - - - - - - -	9	0
Line of micaceous ironstone doggers - - - -	0	9
Shale.		

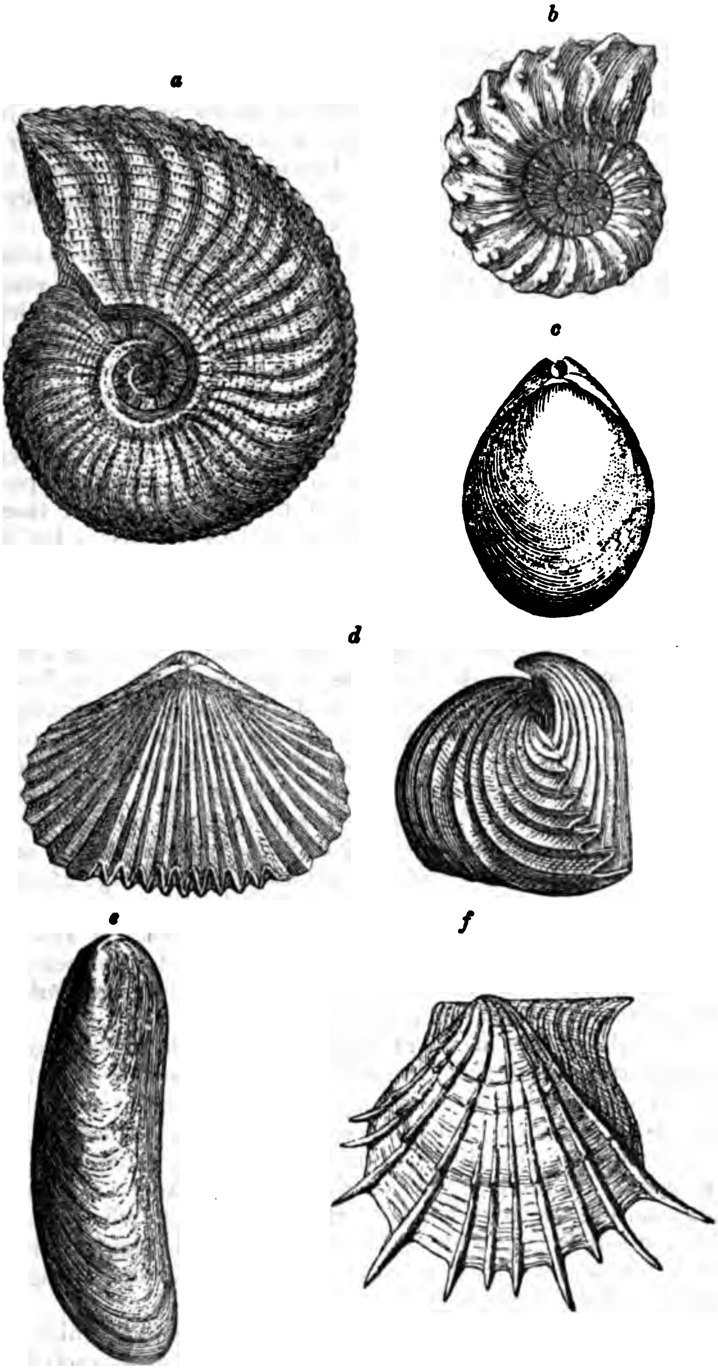
the beds dipping a little W. of N. The sandy shales crop out in several other places in fields and road cuttings, but there are no clear exposures.

There are numerous small stream sections of the Sandy Series in Bransdale, especially in Beck Plantation, Gimmer Bank Wood, and at the southern extremity of the inlier. None, however, show anything of interest.

Farndale shows the largest inlier of the Sandy Series. The sections are of little importance, though sufficient to fix with considerable accuracy the boundary of this division.

The Sandy Series in Rosedale is only represented by two small inliers, exposing about 30 feet of the upper portion. The northern inlier extends along the River Seven from Dale Head Farm nearly to Storrey's House, the banks of the stream showing numerous small sections. A change in the dip carries the beds below the bottom of the valley for half a mile, but they reappear with the same character near Low House, and continue as far as Pry Hills, where a stronger southerly dip rapidly carries them beneath the Alluvium. The best sections are close to Rosedale Abbey, fossiliferous sandy shales appearing in the stream immediately below Bow Bridge, and also near the Foot Bridge leading to Hobb Farm.

FIG. 5.
Middle Lias Fossils.



a, Ammonites margaritatus, *Mont.* (after d'Orbigny) $\frac{2}{3}$; *b*, Ammonites spinatus, *Brug.* (after Wright) $\frac{2}{3}$; *c*, Terebratula punctata, *Sow.* (after Davidson); *d*, Rhynchonella tetrahedra, *Sow.* (after Davidson); *e*, Modiola scalprum, *Sow.* (after Sowerby) $\frac{1}{2}$; *f*, Avicula cygnipes, *Y.* & *B.* (Original) $\frac{2}{3}$.

THE IRONSTONE SERIES.

The Ironstone Series includes the upper portion of the zone of *Am. margaritatus*, and the whole of the zone of *Am. spinatus*; it consists of numerous alternations of shales and ironstone bands. These shales, which are soft and argillaceous in the upper part, become harder and more sandy below; while the ironstone bands, which are thick and important in the north-west, gradually split up and thin away towards the east and south.

This series is the source of all the ironstone which is obtained from the Lias in Yorkshire; a certain amount has been procured from the Oolite above, but it is as nothing compared with the enormous produce of these beds. The history and commercial development of this vast industry has been treated of in numerous papers on the subject, a *resumé* of which we give in the chapter on Economic Geology.

At Peak Steel the base of this series is caught between the two branches of the fault, while on the eastern side the upper part just appears above the surface of the water. Inland there are several small exposures of these beds at the south-east end of Robin Hood's Bay, chiefly under the Peak Alum Works, and along the railway cutting under the Brow. In the latter, flattened nodules, with *Am. margaritatus*, may be seen at the base of the cutting, while the doggers in the upper part contain the large *Pecten* in abundance. From the nearness of the section to the Jet-holes, the *spinatus* beds are probably at the top of the cutting, and consist of soft marly shales of a somewhat mottled appearance, containing doggers, the interior of which is usually filled with liquid mud; *Am. spinatus*, however, was not seen. In the narrow gorge of Howedale Beck there is a complete section of the Ironstone Series to a depth of about 80 feet. The top of the series is here well defined by a band of nodules, with the large *Pecten* and *Pholadomya ambigua*; but *Am. spinatus* was not seen. At some depth below, the nodules occasionally contain the small *Am. margaritatus* (*Am. clevelandicus*), but the lowest beds seen are not so low down as the shales with the larger *Am. margaritatus*, and hence the series must be about 120 feet thick.

The shales here are more argillaceous and decidedly less sandy than further north; and, from the bands of nodules which occur at some intervals being the only representative of the thick ironstones, it is evident that these seams have entirely died out.

From this point, till Hawsker is reached, the outcrop is entirely concealed by Boulder Clay, with the single exception of a small exposure in the south bank of Ramsdale Beck, where about six feet of soft shale, with a band of ironstone doggers, are seen. The fossils are of Middle Lias age, and probably belong to the middle of the series.

At Hawsker Bottoms a complete section is seen which is well displayed both in the cliff and on the scars, so that each bed can be easily measured and described.

Section of the Ironstone Series, Hawsker Bottoms.

		Ft.	In.
(I.)	Layer of earthy ironstone, weathering into rounded doggers: *Pecten æquivalvis* (large), *Belemnites breviformis*, *Pholadomya ambigua*, &c.	0	3
(II.)	Shale, yellow-tinged, soft and finely laminated	2	6
(III.)	Ironstone dogger band; uneven top, very fossiliferous: *Pecten æquivalvis* (large), *Belemnites*, *Ammonites spinatus*, *Am. ferrugineus*, *Modiola scalprum*, *Avicula inæquivalvis*, *Dentalium elongatum*, *Pholadomya ambigua*, *Cardium truncatum*, *Rhynchonella tetrahedra* in nests,* &c.	0	5
(IV.)	Band of finely laminated shaly sandstone, cemented by carbonate of lime and iron, having the fracture of an ironstone. (The "Indurated Shale Band"): *Am. spinatus*, &c.	1	6
(V.)	Grey shale, finely laminated, with sandy streaks and occasional ironstone doggers: *Pholadomya ambigua* and broken specimens of *Am. spinatus*, &c.	6	0
(VI.)	Continuous band of ironstone of irregular thickness: fossils as in No. (III.)	0	6
(VII.)	Shale weathering to small pieces, with occasional ironstone doggers	6	10
(VIII.)	Ironstone band with many fossils, especially *Am. spinatus*	0	3
	Base of high scar at Hawsker.		
(IX.)	Shale	1	0
(X.)	Ironstone band, crowded with fosssils: *Am. spinatus*, *Am. ferrugineus*, large *Pecten*, &c. very abundant; several species of Gasteropoda, &c.	0	4
(XI.)	Hard shale	4	6
(XII.)	Strong band of ironstone, very fossiliferous	0	6
(XIII.)	Hard dark shale, slightly sandy	3	6
(XIV.)	Scattered dogger band	0	3
(XV.)	Shale	2	5
(XVI.)	Continuous band of ironstone	0	6
(XVII.)	Shale, with large *Pecten æquivalvis*, &c. (base of the *Am. spinatus* zone, according to Tate and Blake)†	5	6
(XVIII.)	"Pecten Seam": Continuous band of ironstone with oolitic grains, *Myacites*, &c. 6 in.; Dark micaceous shale, large *Pecten*, *Belemnites*, &c. 8 in.; Hard grey ironstone 4 in.	1	6
(XIX.)	Shale, hard at base, with *Pecten*, &c.	2	0
(XX.)	Ironstone dogger band	0	2
(XXI.)	Shale, with long flat doggers at base	2	4
(XXII.)	Shale, slightly sandy, and containing aggregations of *Pecten*, *Belemnites*, *Gryphæa cymbium*, *Am. margaritatus* (*Am. clevelandicus*, Y. and B.), &c.	18	0
(XXIII.)	Ironstone band, with shale parting in the middle	1	5

* This is quite a characteristic feature of this band, wherever it can be examined.
† The *Am. spinatus* zone probably extends to the base of XXII.; see page 75.

		Ft.	In.
(XXIV.)	Shale, more sandy than above, small scattered doggers containing *Pecten lunularis* and *Am. margaritatus* (?) in large numbers - -	15	0
(XXV.)	Sandy ironstone, resting on a hard sandy band similar to the "Indurated Shale Band": *Gresslya intermedia, Cardium truncatum*, &c. abundant - - - - - -	1	0
(XXVI.)	Shales, very hard and sandy in lower part, softer in the upper, with thin bands of ironstone: Large *Am. margaritatus, Cardium truncatum*, &c. - - - - -	20	0
	Total - -	98	2

At one point, where the cliff is nearly vertical, the entire series was found to measure 103 feet, so that 100 feet may be safely considered the average thickness in this district.

The next point that these beds come above the level of the sea is at Kettleness, where there is the following section.

Section of the Ironstone Series, Kettleness.

			Ft.	In.
Thin cherty bed with nodules, resting on shale; *Am. spinatus, Bel. breviformis; Pecten æquivalvis*, &c. - - -			3	0
Thin cherty bed with ironstone nodules; *Am. spinatus, Bel. breviformis, Pecten æquivalvis* - - - -			0	4
Hard sandy shale, with nodules* - - - -			4	6
Ironstone band - - - - - -			0	3
Shale rather sandy - - - - - - -			1	6
Ironstone; *Am. spinatus, Pecten æquivalvis*,	1	10	Main Seam 6	0
Shale, *Pecten æquivalvis* - - -	2	0		
Shaly ironstone - - - -	2	2		
Shale with occasional fragments of fossil wood - -			1	6
Ironstone 2 inches, Shaly stone 8 ,, Ironstone 7 ,, - - - - - -			1	5
Ferruginous shale, fucoidal markings - - - -			1	2
Ironstone band, many fossils - - - - -			0	8
Ferruginous shale - - - - - -			1	6
Ironstone - - - - - - - -			0	4
Shale, *Pecten æquivalvis, Pleuromya costata* - - -			1	0
Ironstone - - - - - - - -			0	3
Shaly ironstone, *Pleuromya costata* - - - -			0	10
Shale - - - - - - - - -			1	2
Ironstone band, *Am. margaritatus* (*Am. clevelandicus* ?) -			0	6
Shale - - - - - - - - -			7	0
Ironstone band - - - - - - -			0	3
Soft sandy micaceous shale - - - - -			5	0
Total - -			38	2

The ironstone composing the Main Seam is here of poor quality containing only about 26 per cent. of iron. It was, however, torn up off the scars and shipped to the Tyne; but it was not thought to be worth mining, and consequently has not been followed into the cliff. Below the Main Seam, there occur in the district where the ironstone is best developed three other

* From this bed, Messrs. Tate and Blake record the following fossils:—*Am. spinatus, Am. ferrugineus, Chemnitzia Blainvillei, Turbo cyclostoma, Dentalium elongatum, Arcomya arcacea, Inoceramus substriatus, Leda graphica, Leda subovalis, Leda galathea, Macrodon Buckmani*, and *Asturte striatosulcata.*

seams; two of these must be represented in the above section, but they are so split up by shale, as to be almost unrecognisable.*

Immediately under Kettleness village there is a sharp local synclinal, running north and south, in consequence of which the Ironstone Series disappears under the Grey Shale for a short distance, but reappears in Redscar Hole, forming a semicircular patch on the scars. *Am. spinatus*, *Bel. breviformis*, *Rhynchonella tetrahedra*, *Pholadomya*, *ambigua*, *&c.*, are found here. The scars beyond this for some distance are formed of Upper Lias Shales, the next outcrop of the Ironstone Series occurring in the small weed-covered scar of Lingrow Knock. The first line of ferruginous nodules with *Am. spinatus* is seen here at low spring-tides. A fault of 40 feet throws the beds down to the west, to reappear in Brackenberry Wyke, where the Main Seam has been quarried or dug away to a considerable extent. From this point nearly to Staithes, the Ironstone Series forms the scars and base of the cliff. Commencing at Old Nab, and following the beds as they rise, the following section may be made out:—

Section of the Ironstone Series at Staithes.

			Ft.	In.
Earthy ironstone nodules, *Pholadomya ambigua*, &c.			0	3
Shale			1	3
Thin laminated cherty bed			0	6
Sandy shale, rather hard			2	0
Shaly ironstone			0	6
Grey sandy shale			4	0
Ironstone, fucoidal markings at top	2 ft. 6 in.	MAIN SEAM	6	2
Shale	1 " 2 "			
Ironstone	2 " 6 "			
Shale, ferruginous			3	6
Ironstone	0 ft. 3 in.	PECTEN SEAM. Very full of shells especially *Pecten æquivalvis*.	4	5
Shale	0 " 9 "			
Ironstone	0 " 3 "			
Shale	0 " 4 "			
Ironstone	0 " 4 "			
Shale	0 " 8 "			
Ironstone	0 " 7 "			
Marly shale	0 " 9 "			
Ironstone	0 " 6 "			
Shale			2	7
Ironstone, *Am. margaritatus* (*Am. clevelandicus*). TWO-FOOT SEAM			1	9
Shale with occasional ironstone nodules			10	0
Ironstone			0	10
Shale			15	0
Ironstone, AVICULA SEAM			2	0
Shale with variable bed of ironstone, very fossiliferous			1	0
Shales, rather sandy, with rows of nodules or doggers			19	0
Ironstone, very fossiliferous, *Am. margaritatus*			0	6
Soft sandy shale			11	0
Sandy shale, rather hard, with ferruginous nodules			4	6
Thin sandstone, &c. of the Sandy Series.				
			90	9

* It is probable that the five thin beds of ironstone below the Main Seam represent the Pecten Seam, and that the thin band with *Am. clevelandicus* is the Two-Foot Seam, and not the Bottom or Avicula Seam as has been supposed. This latter does not appear to come above the water at Kettleness.

This section may be summarised thus:—

		Ft.	In.
Shale, &c.	- - - - -	8	6
	Main Seam - - - -	6	2
Shale - - - - - - -		3	6
	Pecten Seam - - -	4	5
Shale - - - - - - -		2	7
	Two-Foot Seam - - -	1	9
Shale - - - - - - -		25	10
	Avicula Seam - - -	2	0
Shale - - - - - - -		36	0

The lower beds of shale are probably slightly thinner; the total thickness of the Ironstone Series, when measured with a rope was found to be 85 feet.

The Main Seam has been extensively worked to the south-east of Staithes, but it is now almost abandoned on account of its inferior quality. The other seams have not been worked at all up to the present time.

In the hollow south-west of Staithes the beds are almost entirely obscured by Boulder Clay, but there is a very clear section at the mouth of Grinkle Mine in Easington Beck, which is as follows:—

			Ft.	In.
Two laminated bands with shale, *Pholadomya ambigua*, &c. (section not clear) - - - - - -			5	0
Ironstone	3 ft. 3 in.	Main Seam - - -	6	10
Shale -	1 „ 5 „			
Ironstone	2 „ 2 „			
Shale - - - - - - - -			3	0
Ironstone	0 ft. 4 in.	Pecten Seam? full of shells -	1	6
Shale -	0 „ 9 „			
Ironstone	0 „ 5 „			
Ferruginous shale - - - - - -			2	0
Ironstone - - - - - - -			0	9
Ferruginous shale - - - - - -			4	3
Ironstone, Two-Foot Band - - - - -			1	3

The Pecten Seam may include beds below those bracketed, but the masses of shells only occur in these three.

The Ironstone Series re-appears in Boulby Cliff where the old road below the Alum Works gave the following section:—

			Ft.	In.
Dogger band - - - - - -			0	3½
Ironstone	3 ft. 4 in.	Main Seam - -	6	11
Shale -	0 „ 6 „			
Ironstone	3 „ 1 „			

Just east of Hummersea these beds havs slipped down over the shale scar, so that a continuous section of them is exposed on the foreshore, the stratification being at right angles to their original position in the cliff.

Section shown by the Great Slip near Hummersea.

				Ft.	In.
Dogger band				0	7
Ironstone	3 ft.	6 in.	Main Seam	8	9
Dogger, shaly	1 „	0 „			
Ironstone	4 „	3 „			
Ferruginous shale				2	0
Ironstone	0 ft.	3 in.	Pecten Seam	3	6
Shale	0 „	4 „			
Ironstone	0 „	5 „			
Shale	0 „	6 „			
Ironstone, very fossiliferous	0 „	9 „			
Shale	0 „	3 „			
Ironstone	1 „	0 „			
Shale				4	6
Ironstone, Two-Foot Seam				1	3
Shale				25	0
Ironstone, Avicula Seam				2	0
Shale, &c.					

The lowest beds are broken up and covered by sea-weed, so that the details cannot be seen.

Above Lofthouse Alum Works the ground is obscured by Boulder Clay, but in Hummersea Cliff the Ironstone Series appears again, and there are several small exposures on the east side of Skinningrove Beck near the Lofthouse Mines, where the Two-Foot Seam is 1 ft. 9 ins. in thickness.

In Catterstv Beck there is the following section:—

	Ft.	In.
Base of Main Seam,		
Ferruginous shale	1	6
Shale and ironstone, shelly, Pecten Seam	5	6
Shale	5	6
Ironstone, Two-Foot Seam	2	0

Around Brotton Hill the Ironstone Series is entirely hidden by Boulder Clay, but is seen in the cliff face.

There is a small exposure of these beds at Salt Scar, the extreme north east of the scars opposite Coatham, where sandy shales with ironstone nodules are seen dipping north at 2°. It is evident that the beds are about to change their dip here. Unfortunately, only the base of the Ironstone series is seen, and none of the more important beds of ironstone are on.

In Skelton Beck, just south of the viaduct, there is the following complete section of the whole of these beds, one moreover, that is particularly accessible.

	Ft.	In.
Top dogger (Ironstone), not worked	2	4
Pyritous band, 0 to 3 inches	0	2
Ironstone, Main Seam	9	7
Very ferruginous shale, with doggers	2	5½
Shelly ironstone, Pecten Seam	1	9
Hard dark ferruginous shales	5	7
Ironstone, Two-Foot Band	2	5
Dark shale, with a thin band of ironstone	22	0
Ironstone, Avicula Seam	2	0
Shale, harder and more sandy (about)	25	0
Siliceous ironstone	0	10
Sandy shale, with *Am. margaritatus*, *&c.*	7	6

Below this comes the Sandy Series, the upper beds of which are extremely full of fossils.

The Ironstone Series forms an encircling ring round Hob Hill; but, on three sides, its boundaries are entirely obscured by Boulder Clay. Upleatham Hill is surrounded in a similar manner by the same beds, their upper limit being exposed on the north side in the old ironstone quarries, the section seen being as follows:—

	Ft.	In.
Dogger, an ironstone, pyritous and impure	2	4
Sulphur band (Iron Pyrites)	0	2
Ironstone, Main Seam	9	0
Marbled-stone	0	7
Ferruginous shale (about)	2	0
Shelly-ironstone, Pecten Seam	1	5
Hard dark shale	5	0
Ironstone, Two-Foot Band	2	2

Lower beds than this are not exposed about Upleatham Mines.

In the hollow between Upleatham and Eston Hills the Ironstone Series is obscured by Boulder Clay, but about Court Green the following section may be seen:—

			Ft.	In.
Hard ironstone, impure; used for a roof in mining			3	0
Band of Iron Pyrites, in oolitic grains			0	6
Main bed of blue oolitic ironstone, Main Seam			11	0
Mottled shale and ironstone, in streaks	1 ft. 1 in.	Pecten Seam.	2	10
Dogger (Ironstone) band	0 „ 4 „			
Masses of shells, *Pecten*, *Belemnites*, *Avicula*, &c.	0 „ 5 „			
Mottled shale and ironstone, shelly base	0 „ 5 „			
Shale and ironstone, shelly	0 „ 7 „			

This shelly base of the Main Seam, that is the Pecten Seam, varies much, but, on the whole, thickens as we approach Eston Hill, where it is little less than five feet thick.

On the north side of the Eston outlier there are 7 feet of ferruginous shales beneath this, with the Two-Foot Seam below, but these are the lowest beds that are seen here. On the south side of this hill the entire series is cut out by the great Upsall fault as far as Scugdale; beyond which the Main Seam comes in again, and in an opening for ironstone there is the following section:—

	Ft.	In.
Base of Main Seam, looks like a red gravel	—	
Mottled shale with streaks of ironstone	1	0
Shales, crumbles to small pieces	2	0
Shelly beds, with ironstone and shale partings, Pecten Seam	2	4
Ferruginous shale	5	8

From the above it will be seen that on the south side of Eston Hill the Pecten or Shelly Seam is not immediately under the Main Seam, as on the north side; but is separated by three feet of ferruginous shale, and cannot, in consequence, be mined with the latter seam, as is proved in Chaloner's Pit.

At Tockett's Lythe, the solid rocks come once more to the surface, the hill being composed of the lower beds of the Series. The Main Seam is commonly believed to exist here, but such is not the case. A little south of Waterfall there is an exposure of shale, with ironstone; while further up the stream, and in the railway cutting, there is a nearly complete section of the Ironstone Series. It is as follows, in descending order:—

			Ft.	In.
Ironstone, much quarried, MAIN SEAM			—	
Shale, with thin streaks of ironstone			4	6
Ironstone, with shale	1 ft. 2 in.	PECTEN SEAM	4	0
Shelly ironstone	0 „ 9 „			
Ferruginous shale	0 „ 2 „			
Ironstone, shaly and shelly, *Pecten, &c.*	1 „ 5 „			
Shelly ironstone	0 „ 6 „			
Crumbly shale			5	0
Ironstone, *Am. clevelandicus*, TWO-FOOT SEAM			2	6
Light sandy shale			6	0
Sandy ironstone			0	3
Sandy shale			19	0
Hard ironstone, AVICULA SEAM			1	10
Sand shale			5	0
Thin sandstone, *Pecten lunularis*			0	4
Hard sandy shales			6	0

The Ironstone Series may be easily followed in the lower part of the great hill, south of Guisbrough; where there are many small exposures, principally of the upper beds, the best of which occur about Belman Bank. In the neighbourhood of the old Hutton Mines the workings have exposed several clear sections, from which the following has been compiled:—

	Ft.	In.
Ironstone, MAIN SEAM	—	
Ferruginous shale, with thin streaks of ironstone	4	4
Ironstone with bands of *Pecten*, PECTEN SEAM	3	6
Green shales	2	8
Ironstone, hard, TWO-FOOT SEAM	2	7
Green shale	6	6
Blue oolitic ironstone	1	0
Sandy shale, with finely laminated sandstone	20	0
Thin band of sandy ironstone	—	
Soft sandy shale	20	0
Hard sandy shale	10	0
Sandy shale, with ferruginous doggers, containing many fossils	6	0

Further west and south the beds below form a bold flat-topped escarpment, in consequence of which there are no natural sections of the Ironstone Series, the few trial-holes for the Main Seam being the only positive evidence. The shape of the ground, however, shows very clearly the position of the upper part of the Middle Lias. The whole of the Middle Lias is exposed in the whinstone quarries at Cliff Ridge, but the strata are so calcined that it is not a good place for examination. Circling round Easby Bank, on which Captain Cook's Monument stands, the upper beds are clearly seen just above Burrow Greens, but beyond this a quantity

of detritus obscures the ground as far as the old Kildale Mines. The workings here have exposed the following section:—

			Ft.	In.
Lenticular hard shale and doggers			1	0
Hard shale			1	10
Indurated shale band			0	3
Sulphur band			0	2
Ironstone	2 ft. 3 in.	Main Seam	4	10
Shale	1 „ 1 „			
Ironstone	1 „ 6 „			
Ferruginous shale			3	8
Shelly ironstone, *Am. spinatus*, *&c.*	0 ft. 11 in.	Pecten Seam	2	6
Shale	0 „ 2 „			
Ironstone, *Pecten*, *Avicula*, *&c.*, in masses	0 „ 2 „			
Shale	0 „ 3 „			
Ironstone, few fossils	0 „ 6 „			
Shale	0 „ 3 „			
Ironstone	0 „ 3 „			
Shale			2	2
Ironstone, Two-Foot Seam			2	5
Shale.				

Along the Ingleby escarpment the covering of gravel and detritus conceals the outcrop of the Ironstone Series for some distance, and the only reliable information is to be gained from the Ingleby Mines, at which the following section was measured:—

			Ft.	In.
Shale with rows of ironstone nodules.				
Dogger band			0	3
Hard, grey ironstone	2 ft. 0 in.	Main Seam	4	10
Shale parting	1 „ 4 „			
Hard, grey ironstone	1 „ 6 „			
Shale parting			0	4
Shaly ironstone, Pecten Seam			1	8
Shale			2	9
Ironstone, Two-Foot Seam			2	0

There is no doubt that this last seam of ironstone is the Two-Foot Seam, as it contains *Avicula cygnipes*, a small *Pecten*, *Cardium truncatum*, *Am. clevelandicus*, &c., while *Am. spinatus* and *Pecten æquivalvis* are absent.

On the face of the escarpment the great landslip at Blue Bell Trough exposes the following section:—

			Ft.	In.
Ferruginous shale, resting on hard shale band			3	0
Impure oolitic ironstone	1 ft. 3 in.	Main Seam	9	9
Ferruginous shale	3 „ 0 „			
Shale with dogger bands	4 „ 0 „			
Ironstone, very hard	1 „ 6 „			
Laminated shale			6	0
Shale, darker and softer			12	0
Ironstone, with shale parting			0	9
Ferruginous shale			3	3
Thin, sandy ironstone, *Cardium*, *Pecten*, &c.			0	3
Shale, ferruginous, sandy towards base			30	0
		Total	65	0

From this section the Main Seam, which is well known from its character, is evidently split up into two widely separate blocks; the Avicula or lowest Seam is perhaps in the upper part of the last 30 feet of shale, but covered by rubbish.

Just before entering Bilsdale, ferruginous shales are seen close against the boundary wall at the head of the dale, and the first seam of ironstone is seen about a hundred yards to the south-west. The outcrop of the Main Seam continues clear for about three-quarters of a mile as far as the hamlet of Urra, and sections may be seen in both branches of the stream that flows down past The Holme, that at Cast Hills being as follows :—

Section of the Ironstone Series at Cast Hills.

	Ft.	In.
Ironstone	0	3
Shale	1	6
Ironstone	0	4
Shale	0	3
Ironstone,* probably Two-Foot Seam, with *Pecten lunularis*, *P. æquivalvis*, *Cardium truncatum*, *Avicula cygnipes*, *A. inæquivalvis*, *Myacites* sp. and *Belemnites* sp. abundant	1	6
Shale	14	0
Ironstone, probably Avicula Seam	2	0

South of this the Main Seam and the Avicula Seam are seen opposite Chop Gate, and there are exposures of ironstone at Ellermire, Cam House, and Oak House. In Tripsdale the Avicula Seam, which is 2 feet thick, crosses the stream about half a mile above Hagg House.

In Tarn Hole Beck there is the following section :—

	Ft.	In.
Ferruginous shale	5	0
Ironstone	0	5
Shale	2	0
Ironstone, Two-Foot Seam	1	3
Shale	3	6
Sandy band	0	4
Shale	4	0
Ironstone	0	4
Micaceous sandstone	2	0
Shale	12	0
Ironstone, Avicula Seam	1	9
Shale	5	0

It is noticeable here that the shales between the Two-Foot and Avicula Seams are decidedly more sandy, a feature that becomes more pronounced as we proceed in a south and west direction. The Main Seam is not exposed in this section. Further south the principal exposures of the Ironstone Series are in the roads by Appletree Hurst and Low Crosset; while in Crosset Plantation there are a number of old workings, but they are so ancient that no record of them is known in the dale.

The beds descend rapidly from this point, and one of the ironstone seams crops out at the first sharp bend of the river north of

* From the fossils and the general character of the beds there can be little doubt that this is the Two-Foot Seam. The Main Seam was met with in a trial-hole above; but this has fallen in, so that no details could be ascertained.

Spout House; while at the next bend below, ferruginous shale, evidently near the top of the series, is seen.

On the west side of the dale the greater part of the Ironstone Series is exposed in Fangdale Beck, and a trial-hole, partly fallen in, gives the following section of the Main Seam:—

	Ft.	In.
Ironstone	1	0
Shale	3	0
Ironstone	1	0

In Stingamire Gill a trial-hole has been made in which three seams of ironstone can be seen; the lowest being of the best quality and about 1 foot 6 inches thick.

North of this the ironstone is seen at a few places along the hillside, but the best exposure is close to the south end of Vittoria Plantation, where the following section occurs:—

	Ft.	In.
Shale with ironstone streaks	2	0
Mixed shale and ironstone	1	10
Shale	2	0
Ironstone	0	2
Shale	1	8
Ironstone	0	4
Ferruginous shale	0	6
Ironstone	1	0

At the north-west point of Dromonby Hill the seam forms a considerable spread, the ground being covered with fragments of ironstone. A trial-drift was made here, but has fallen in. The base of the seam, which is a marly ironstone, caps the scar at the head of Tom Gill and the following section is seen:—

Section at Tom Gill, Busby Moor.

	Ft.	In.
Base of Main Seam		
Dark ferruginous shale	6	0
Flaggy ferruginous siliceous nodules	0	4
Ferruginous shale	12	0
Hard, oolitic ironstone, Avicula Seam	1	3
Ferruginous shale, harder at base	31	0

Passing down the valleys at the head of Raisdale, the Ironstone Series has a well-defined outcrop; but rock exposures are rare, owing to the thick covering of downwash, and to the fact that no trial-holes have been made till the two streams unite. Just at this junction is a drift, which has now fallen in, but from which Messrs. Tate and Blake give the following section of the Main Seam:—*

		Ft.	In.
Main Seam	Ironstone, with dogger band at top and base	2	8
	Shale	1	5
	Ironstone, with dogger band at top	1	9

Just south of this there is a fault which throws up the Ironstone some distance to the south side, so that the Main Seam crops out in the road close by High Crosslets, and the beds below have been exposed by denudation. The outcrop on the south

* The Yorkshire Lias, p. 140.

side of Raisdale is quite clear, and in Harton Gill the following section may be seen:—

Section of the Ironstone Series in Harton Gill, Raisdale.

		Ft.	In.
Thin indurated sandy band.			
Shale		4	0
Indurated band		0	6
Shale		1	0
Sulphur band		0	1
Ironstone dogger		0	4
Shale		1	0
Ironstone*	Main Seam	4	0
Shale*			
Ironstone, 2 feet			
Shale		6	0
Ironstone, Two-Foot Seam		0	9
Shale		6	0
Laminated sandy ironstone (*Cardium truncatum*)		0	3
Shale, well-bedded		10	0
Ironstone, Avicula Seam		0	9
Shale with few doggers		25	0
Total		60	8

The hard, laminated, sandy, ironstone band, crowded with *Cardium truncatum*, is very characteristic in this area. Its hardness often causes it to have a bare outcrop, and from it the position of the Main Seam can be fixed, even when the latter, as is often the case, is quite obscured by downwash.

At the head of the small beck south of Breck House a trial-hole was made, which has since fallen in. Here the bottom band of ironstone is 2 feet thick, and of an oolitic, shelly character; while above are two other bands of ironstone, harder and more siliceous. The thickness of the whole with shale partings is about 6 feet.

Returning once more to the main escarpment, the feature alone marks the position of the Ironstone Series along the west face of Carlton Bank, and no trial-holes occur till Swainby Mines are reached, where the following section was proved:—

Section at the Ironstone Mines, Swainby.

			Ft.	In.
Hard sandy ferruginous beds			3	6
Sulphur band (iron pyrites)			0	1
Flaggy sandy bed			0	10
Sulphur band (iron pyrites)			0	1
Ironstone	3 ft. 4 in.	Main Seam	6	0
Shale	0 „ 10 „			
Ironstone dogger	0 „ 4 „			
Ironstone	1 „ 6 „			
Hard black shale			2	3
Dogger band			0	4
Softer dark shale			3	0
Sandy hard shale			7	0
Softer shale			4	0
Hard white ironstone			1	10

* Obscured by rubbish.

Passing up Scugdale the outcrop of the Ironstone Series is faulted out for some little distance, but the ironstone was proved by two drifts further east, both of which showed the Main Seam to deteriorate in this direction. This is well shown by the section at the head of the dale, which is as follows:—

Section of the Ironstone Series at the Head of Scugdale.

		Ft.	In.
Indurated shale band.			
Shale, soft and ferruginous		7	0
Ironstone		0	9
Shale		2	6
Ironstone - 1 ft. 8 in.	Main Seam	4	5
Shale - 0 „ 9 „			
Ironstone - 2 „ 0 „			
Shale, soft and ferruginous		3	0
Small dogger band		0	3
Shale, ferruginous		3	6
Ironstone, blue, oolitic, and very fossiliferous,	Two-Foot Seam	1	2
Soft shale		4	4
Laminated sandy ironstone		0	6
Soft ferruginous shale		4	6
Small dogger band		0	3
Shale		3	0
Oolitic white ironstone, *Avicula*, *Pecten*, *&c.*,	Avicula Seam	0	9
Shale, rather sandy		2	0
Ironstone, with erect *Myacites*		0	9
Shale		0	6
Doggers		0	3
Hard sandy shale		2	0
Ferruginous shale		15	0
		56	5

Though the position of these beds may be easily followed on the south side of Scugdale there are no clear outcrops nor trial-holes, and it is not till Limekiln Bank is reached that the beds are again seen *in situ*. The Main Seam has been worked by drifts in different parts of this wood, but the ironstone is considerably thinner than in the present Swainby mines, and was consequently abandoned. Below one of the drifts part of the beds beneath the seam are exposed, but not sufficiently clearly to be measured.

Close by Scarth Nick the Ironstone Series are thrown down between two north and south faults, the eastern of which has a throw of more than 100 feet; between these two faults the position of all the Lias beds is very difficult to fix. Just to the west of the second fault a small ditch shows:—

	Ft.	In.
Shales.		
Ironstone, Two-Foot Seam	1	0
Shales, about	20	0
Ironstone, Avicula Seam	1	4

This is the last clear evidence of these seams about the Arncliffe Woods. In the little outlier of Whorl Hill the jet pits show sufficiently clearly the position of the Ironstone Series, but there are no good exposures.

In Cod Beck near Thimbleby Lodge, the following section is seen :—

			Ft.	In.
Hard shale band			0	6
Shale with small doggers			4	0
Ironstone	2 ft. 0 in.	Main Seam	4	4
Ferruginous shale	1 „ 4 „			
Ironstone	1 „ 0 „			
Shale			10	0
Ironstone, full of small fossils, Two-Foot Seam			1	6
Shale			20	0
White ironstone, Avicula Seam			0	6
Shale			10	0
Thin, lenticular, ferruginous sandstone			1	0
Sandy shale			2	0
Thin sandstone			2	0
Shale			1	0
Thin sandstone			2	0
Shale			6	0
Main bed of sandstone (Sandy Series).				

The occurrence of alternating flaggy sandstones and sandy shales in the lower part of the Ironstone Series is well seen here. As we proceed south the whole series becomes so arenaceous that it was found impracticable to separate these beds from the Sandy Series below. Along Thimbleby bank all the upper beds of the Middle Lias are obscured by Drift, the only section being in a small hollow to the S.E. of Nun House, where a thin seam of ironstone is seen, probably the Avicula or lowest, about one foot in thickness. From this point the outcrop of the Middle Lias gradually sinks below the Drift, except a doubtful exposure near Upsall Castle which must be about the junction with the Sandy Series.

It is not till Feliskirk is reached that the Ironstone Series is seen again. In the sharp bend of the road above the Church, ironstone, which is evidently part of the Main Seam, is exposed, and the Grey Shales of the Upper Lias come on immediately above. A boring was put down on the top of the hill to prove the ironstone in this district and gave the following section* :—

		Ft.	In.
	Oolitic iron-rock	7	0
	Upper Lias shale	116	0
Middle Lias.	Nodular ironstone	0	7
	Soft shale	3	0
	Nodular ironstone	0	6
	Shale	7	6
	Marlstone	1	9
	Sandy shale	20	9

The whole of the beds below the bands of nodular ironstone given here, belong to the Ironstone Series not to the Sandy Series; the gradual change of the former to an arenaceous deposit is referred to in describing the Thimbleby section.

There are only two isolated exposures of the Ironstone Series near Sessay, where the Middle Lias is let down by two faults between New Red Marls. The first of these is close to Sessay

* Prof. J. Phillips, Quart. Journ. Geol. Soc., vol. xiv. p. 96.

Station, in the railway cutting at the "Darlington 27" mile-post, where gravelly ironstone has been dug out, while a few yards to the south the platy Jet Rock is seen. The other outcrop is at Barf Hill, the summit of which is covered by a similar gravelly ironstone. There must evidently be some thickness of the bed here, but how much is not clear.

Inliers of the Ironstone Series.

In the dales the Ironstone Series varies in thickness from 60 to 90 feet, and consists of soft, dark, ferruginous shales, with thin bands of ironstone of variable thickness; the lower portion is hard and sandy, while the upper is grey, softer and more earthy, and apparently forms a lithological passage into the Upper Lias. In the more westerly dales seams of oolitic ironstone occur, but, in the absence of mines, the positive correlation of the thin seams in these valleys, with the more important beds of Cleveland, is scarcely safe. Probably there is a representative of the Main Seam in all these inliers, but in several of them none of the other seams could be recognised.

In the Esk valley the Pecten and Avicula are the principal seams, and in fact the only ones that are worked. Towards the eastern end of the dale the series first appears in Iburndale in the bed of Little Beck, at Shaw Head; where the upper part, and its relation to the Upper Lias may be well seen. The bank above, on the west side of the stream, consists of soft Grey Shale, with decomposed earthy nodules, while near the base there is a small row of ironstone doggers with *Pholadomya ambigua*. Two feet below this is the representative of the "Indurated Shalé Band," so well developed at Hawsker, but which here consists merely of sandy micaceous laminæ, and is about three inches thick.

Further down the stream at Throstle Nest, and again a few hundred yards further north, the Pecten Seam crops out, the following being the section:—

	Ft.	In.		Ft.	In.
Ironstone - - -	0	10	Pecten Seam* -	2	4
Shale - - -	0	4			
Ironstone - - -	1	2			

Below this is a bank of shale with several thin ironstone dogger bands, the whole about 20 feet in thickness.

The section here is not cut to a sufficient depth to show the Avicula Seam, but the rock next exposed further down the stream consists of the rather hard sandy shales below it; while the seam itself may be seen at the first sharp bend in the stream below Iburndale village, and again, dipping sharply north-east, at the railway bridge. Here the section is:—

			Ft.	In.
Shales, ferruginous and lumpy - - - -			8	0
Hard ironstone - -	0 ft. 10 in.	Avicula Seam	2	0
Softer stone, shelly in upper part	1 " 2 "			
			10	0

* This will not be so thick further from the outcrop.

A small stream that flows down the east bank of Iburndale from Ugglebarnby exposes part of the Ironstone Series, probably just above the Pecten Seam, as a trial-hole has been driven in, exposing now only the top of a seam of ironstone, which, however, has not been worked.

On the north side of the Esk, opposite Sleights Bridge, a shaft was sunk about 33 feet to a seam of ironstone, probably the Pecten Seam; which was worked for several years, and about 11,000 tons were produced after which the mine was abandoned. The seam was three feet thick, with a shale parting of one foot in the middle. In the north bank of the river, a little further west, both seams crop out; but the ground is so much obscured by vegetation and clay, that it is impossible to give a detailed section of them. From this point the middle of the Esk valley is completely covered with Boulder-clay and gravel, to a depth in some cases of 200 feet, so that the position of the Ironstone Series can only be conjectured.

On the south bank, however, there are several exposures, the seams being also proved by mining at Eskdale Gate, where the section of the Pecten Seam is:—

	Ft.	In.
Ironstone - - - - - - - -	0	6
Shale - - - - - - - - -	1	3
Ironstone - - - - - - - -	1	10
	3	7

The Avicula Seam consists of a solid block of ironstone, two feet thick. A few small exposures occur in the hollow between Galey House and the old Alum Works; and both seams have been tried immediately under the new Alum Works. But in all these cases the seams have proved too thin and too poor in quality to be long worked at a profit.

The following is the general section of these beds in the neighbourhood of Grosmont:—

Section of the Ironstones near Grosmont.

	Ft.	In.
Indurated shale band, few ironstone nodules above -	0	5
Shale with a few nodules and doggers—*Am. spinatus*, *Pecten æquivalvis*, &c. - - - - - - - -	5	0
Lenticular, sandy, ironstone band - - - - -	0	6
Shale - - - - - - - - -	3	4
Ironstone* with the large *Pecten æquivalvis*, *Belemnites*, &c.	1	0
Shale with large round doggers full of fossils - -	13	0
Ironstone 0 6, Shale 1 3, Ironstone 1 10 } Pecten Seam - - - - -	3	7
Shale, hard, dark, and sandy - - - - -	3	6
Two-Foot Seam.—Ironstone, hard calcareous, and oolitic—*Am. clevelandicus* - - - - - - -	0	10
Shale - - - - - - - - -	25	0
Avicula Seam.—Ironstone - - - - - -	2	0
Shale, rather sandy - - - - - - -	6	0
Band of hard, sandy shale - - - - - -	0	6
Hard shale, rather sandy - - - - - -	25	0
	89	8

* This is probably the representative of the Cleveland Main Seam.

The upper part of the above section was measured in the bed of the river just by the south end of the tunnel; the rest was measured just north of the mines.

There is a point of special interest in this section in the Murk Esk. The Pecten Seam does not contain the same fossils as the Main Seam of Cleveland, but it does contain the same as the shelly ironstone at the base of the seam at Eston. In fact, both in its fossils and mode of occurrence, the Pecten Bed shows itself clearly to be the same as the Eston shelly bed, and from this we infer that the Cleveland Main Seam is not the same as the Pecten Seam, but is above the latter. It has been stated, apparently without any good reason, that the Main Seam, which splits up into two as it passes eastward, is represented at Grosmont by the Pecten and Avicula Seams together.

In this case we should clearly expect that the two seams would pass continuously under the North Cleveland Hills and unite to the west. In reality, however, the Main Seam is represented at Grosmont by a band of impure ironstone only a foot in thickness, and it becomes at once evident that we must go a long way to the west before it will have thickened sufficiently to be of any economic value.

The Pecten and Avicula Seams have been mined for some years past in the neighbourhood of Grosmont, but in consequence of the thinness and poor quality of the ore, several of these mines have been abandoned.

At the present mines the Pecten Seam is usually a shelly and somewhat shaly ironstone, gradually falling to pieces on exposure to the air. Its thickness is about 3 feet 6 inches, but only 2 feet 4 inches of this are workable ironstone, yielding an average of 26·5 per cent. of metallic iron.

This seam first appears at the junction of the Murk Esk and Lythe Beck, and is of the usual shelly character; it, however, soon dips beneath the stream under the railway bridge, and its outcrop being concealed by the buildings and rubbish heaps about the ironworks, is not again seen till a small gully is reached just above the next railway bridge to the north, where a similar section occurs. Further east the two seams were mined by the Whitby Stone Company; the Pecten Seam yielding about 2 feet 6 inches of ironstone.

The Avicula Seam rises from the river bed under the railway bridge north of the furnaces, but its exact thickness cannot be determined. The small *Ammonites clevelandicus* is abundant here, as is also *Pecten lunularis* and several other fossils, but they are rather decomposed. Sections of this seam may be seen in almost all the small gullies on the south side of the river, the usual thickness of the ironstone being about 3 feet 6 inches, but on the north side of the stream the Boulder Clay is so thick that no natural sections occur. At Grosmont Mines the usual thickness of ironstone is about 2 feet 6 inches, but in the mine on the opposite bank of that river it is 3 feet 6 inches thick. Both seams were proved in a shaft sunk about half a mile south of Grosmont,

known as the Esk Valley Mine, where the two seams were proved at a depth of 64 and 70 yards respectively, the Pecten Seam being 3 feet thick and the Avicula Seam about 2 feet.

In Glaisdale the only section which can now be examined is in West Arnecliffe Wood. Here the beck has left the old valley, which is now filled with Drift, and has cut a gorge through solid rock. About 10 chains east of Bank House Beck there is:—

		Ft.	In.
	Grey shale with earth doggers containing *Ammonites annulatus*	10	0
I.	Row of ferruginous limestone doggers, tough, fracture rather earthy, fossiliferous: *Belemnites*, &c.	0	4
II.	Hard shale	4	0
III.	Row of very irregular ferruginous limestone doggers, fossiliferous	0	6
IV.	"Indurated shale" band	1	6
V.	Hard shale	2	0
VI.	Limestone, like I., but not so calcareous	0	8
VII.	Shale with occasional *Belemnites*	1	4
VIII.	Limestone, effervescing strongly, crowded with fossils often filled with zinc-blende	0	6
IX.	Shale	3	0
X.	Large lenticular doggers 4 ft. or 5 ft. across and 10 in. thick, no fossils observed (like VI.)	0	10
XI.	Shale with occasional *Belemnites*	2	4
XII.	Lenticular doggers rather closer together than X. The shale on the same horizon contains a large *Pecten* and other fossils	0	6
XIII.	Shale	1	0
XIV.	Ironstone, decomposed	0	4
XV.	Ironstone, slightly oolitic, effervescing faintly	1	2
XVI.	Ironstone, decomposed	0	1
XVII.	Shale	2	0
XVIII.	Ironstone, very fossiliferous and oolitic	1	7
XIX.	Hard shale	0	4
XX.	Row of large flat doggers, fine grained, not calcareous, fossils rare	0	6
XXI.	Shale	1	6
		36	0

The ironstone XIV. to XVIII. is not worth working, being thin, though of fairly good quality.

The following is the section of the abandoned pit at Glaisdale*:—

		Ft.	In.
Boulder Clay	Clay	53	0
Alum Shale	Shale and cement doggers	67	0
Base of Alum Shale and Jet Rock.	Jet rock	58	0
Grey Shale	Dogger	0	6
	Grey shale	5	0
	Dogger	0	6
	Grey shale	14	0
	Dogger	0	6
	Grey shale	3	0
	Dogger	0	6

* Communicated by Mr. Bell of Swainby Mine.

				Ft.	In.
Ironstone Series.	Hard shale [" Indurated shale"]			1	6
	Pure shale			2	0
	Dogger			0	4
	Shale			1	8
	Small seam of stone with *Pecten*			0	6
	Shale			2	0
	Nodules			0	8
	Shale			4	0
	Nodules			0	6
	Ironstone	0 ft. 6 in.	Pecten Seam	6	7
	Shale	0 „ 8 „			
	Ironstone	1 „ 0 „			
	Ironstone, mixed	0 „ 9 „			
	Shale	2 „ 6 „			
	Ironstone	1 „ 2 „			
	Shale			6	0
	Hard shale, slaty and gritty			6	0
	Shale			15	6
	Ironstone	0 ft. 4 in.	Bottom Band	5	0
	Shale	0 „ 8 „			
	Ironstone	1 „ 6 „			
	Shale	1 „ 6 „			
	Ironstone	1 „ 0 „			
			Total	254	3

Mr. Parker gives the Pecten Band in this mine as—

	Ft.	In.
Ironstone	0	5 to 6
Shale (often wanting)	0	1 to 3
Ironstone	1	4
Black ironstone band	0	5
Shale	2	6
Ironstone	1	4

Some of the stone may still be seen near the furnaces, but the quality is so poor that it is surprising that it should ever have been worked.

The rest of the Ironstone Series in Glaisdale is hidden by Drift, with the exception of two small exposures where gills cross the road on each side of Hob Garth.

There are no good sections of this series in Fryup Dale, but a seam of oolitic ironstone can be traced through great part of Little Fryup. Where it crosses High Lane there is:—

	Feet.
Shale.	
Ironstone, fossiliferous, oolitic	about 1
Hard shale with lines of very tough unfossiliferous doggers	about 8
Ironstone, fossiliferous.	
Sandy shale.	

The seam, though only a few inches thick, appears to have been worked in former days, as there are several slag-heaps in different parts of the dale, and remains of the old furnaces have been found in Fairy Cross Plain. A thicker seam can be traced

for a few yards in Rabbit Slack at the head of Great Fryup. The section is:—

	Ft.	In.
Grey shale.		
Shale with small doggers - - - - - -	8	0
Large lenticular ironstone doggers - - - - -	0	6
Shale - - - - - - - -	2	6
Ironstone, fossiliferous - - - - - -	1	7
Shale with flat pyritous doggers.		

This probably represents the Main Seam, but the one in Little Fryup appears to be on a lower horizon and cannot satisfactorily be correlated with any of the named seams.

In Danby Dale the thin ironstone reappears near Lumley House, at Nook House, and at Stormy Hall, though it cannot be measured at any of these localities. There are good sections of the accompanying shale near Smallwoods House, and at Mill Scroggs at the lower end of the dale.

The only clear section of the Ironstone Series in the eastern branch of Westerdale is to be seen in the gill immediately south of Swarthy Hill:—

	Ft.	In.
Shale - - - - - - - -	1	0
Ironstone doggers - - - - - - -	2	3
Shale - - - - - - - -	0	3
Ironstone doggers - - - - - - -	0	3
Shale - - - - - - - -	0	9
Ironstone, oolitic, fossiliferous - - - - -	0	0
Shale and lines of tough doggers - - - -	8	0
Total - - -	13	0

In the western branch of the dale the Main Seam is well shown in a trial-hole a quarter of a mile north-east of Low Farm. Though rather obscured, the sections seem to be:—

	Ft.	In.
Very ferruginous shale and shaly ironstone - - -	5	0
Shale - - - - - - - -	1	0
Ironstone, oolitic, fossiliferous - - - - -	2	2
Hard shale - - - - - - - -	2	0
Total - - -	10	2

On the opposite side of the beck, immediately east of the fault, there is a good section of the beds beneath the ironstone:—

	Ft.	In.
Soft grey shale - - - - - - -	4	0
Hard ferruginous shale with ironstone doggers and *Pecten* -	1	4
Ironstone shale - - - - - - -	0	8
Line of doggers - - - - - - -	0	3
Ironstone shale - - - - - - -	4	0
———? (hidden) - - - - - - about	10	0
Ironstone shale - - - - - - -	4	0
Ironstone, with fossils - - - - - -	0	3
Ironstone shale - - - - - - -	7	0
Ironstone, fossiliferous, with pyrites and *Avicula*? - -	0	8
Ironstone shale - - - - - - -	4	0
Total - - -	36	2

The plateau on which Westerdale Church stands is formed by the ironstone, here about a foot thick, and the pits so numerous in the neighbourhood mark the position of old workings. Ironstone, probably the same seam, can be traced for a about half a mile near Stockdale House ploughed up in the fields. Near Waites Moor a change in the dip carries the Ironstone Series beneath the stream, but a small anticlinal at Esklets again brings up a few feet of these beds.

The Ironstone Series in Basedale is divided into two inliers, neither of large extent. The northerly one, on which Basedale Abbey is situated, shows a 4-inch seam of oolitic ironstone with *Belemnites* and a large *Pecten*, in the beck a furlong south of the Abbey. In the middle of the southern inlier there is a good section near the stream:—

	Ft.	In.
Jet Rock.		
Grey Shale, very like ironstone shale - - -	25	0
Line of small doggers with *Ammonites annulatus*.		
Shale - - - - - - - -	3	0
Doggers in harder shale (" Indurated shale band ") - -	0	8
Ironstone shale - - - - - - -	11	0
Shale with lines of scattered septaria - - -	3	0
Ironstone shale with a few scattered septaria - -	5	0
Total - -	47	8

The only exposure in Bransdale is in a trial-hole near the northern end of Gimmer Bank Wood, where 16 inches of poor ironstone was found. Similar ironstone can be seen in the road above Mason House. In both cases it may represent the Main Seam.

A seam of oolitic ironstone measuring 10 or 11 inches can be recognised in various parts of the northern half of Farndale, but there are no continuous sections of the associated shales, and no means of correlating the seam with those found in other dales.

In Rosedale a section in the stream near Dale Head shows:—

	Ft.	In.
Ironstone shale and doggers - - - -	8	0
Ironstone, fossiliferous - - - - -	1	2
Ironstone shale and doggers - - - -	5	0
Total - -	14	2

A 6-inch seam of oolitic ironstone, possibly representing the thicker seam of the above section, can be examined in the beck near High House; it is also found near Bell End Houses, and can be traced for a short distance near Abbey Heads.

Returning again to the main outcrop south of the great faults we find the Middle Lias skirting along the hill side to the south of Coxwold; and forming a good feature, especially at Husthwaite, where the sandstone is exposed.

Beyond this the beds are depressed by a fault so that the next exposure is at the village of Thormanby, where there is a good section of the sandstone and limestone with bands of fossils,

principally *Cardium truncatum*, *Avicula cygnipes*, and *Pecten æquivalvis*, seen in the road dipping at an angle of 4 degrees to the south-east.*

West of Thormanby the Middle Lias passes beneath the sands and alluvium of the flat, and from the general strike of the other beds probably curves round by Boscar Grange and Peep-O'Day, although nothing is seen of the bed in this region; the first section we get being at the stream a little beyond Swallows Nest, where marly sandstone is seen apparently striking in this direction. South of this it spreads out towards Easingwold, and forms a strong feature below Rising Sun, where the sandstones are exposed, as also they are in the little gully to the east; and just above at the foot of Howe Hill there are fragments of oolitic ironstone from the upper part of this formation.

At the side of Haverthwaites Beck a borehole was sunk in search of coal apparently in these beds, but of this we could obtain no account. Prof. Blake mentions having found *Rhynchonella tetrahedra* in fragments of oolitic ironstone from this boring.†

About a mile east of this the sandy beds are seen in Britton Wood, beyond which they are thrown up by a large fault so that the main outcrop forms a well-marked terrace along the hillside east of Brandsby; while a large outlying patch occurs along the hill to the south from Crayke to Stillington. In this outlier the Middle Lias is fairly well exposed, beds of siliceous sandstone, containing *Rhynchonella tetrahedra*, *Cardium truncatum*, and *Avicula inæquivalvis*, and ironstone being seen at Halfway House and in the lane beyond. Between Crayke and Stillington the beds are hidden by Boulder Clay, but at the latter village, where the wells go through about three yards of sand and rock and then into shale, they are again exposed. On the hill to the south, and near the Mill, ferruginous beds with *Cardium truncatum* are seen.

The main outcrop east of Brandsby forms a conspicuous terrace as far as Terrington and Mowthorpe, and the rock is very well seen at several places. It consists in the main of sandy shales and sandstones with calciferous doggers full of fossils, of which the principal are *Rhynchonella tetrahedra*, *Avicula inæquivalvis*, *Gryphæa cymbium*, *Pecten æquivalvis*, *Cardium truncatum*, *Hippopodium*, *Isocardia*, *Myacites*, &c. Above this is a greater or less thickness of soft shale with bands of ironstone doggers.

Along this range of hills the thickness of the Middle Lias rapidly decreases from about 70 feet in the west to not more than 30 feet, while further east beyond the Derwent, as we shall see presently, it thins out altogether.

In the valley to the east of Mowthorpe, the terrace formed by the Middle Lias is cut off by a large fault, but reappears on

* Messrs. Tate and Blake also mention *Macrodon Buckmani*, *Dentalium giganteum*, *Rhynchonella calcicosta*, and species of *Leda*, *Gresslya*, &c., from this locality. The Yorkshire Lias, p. 112.

† The Yorkshire Lias, p. 142.

the hillside to the south below Stittenham, and from thence may be traced uninterruptedly to Whitwell.

Capping the hill above Thornton-le-Clay is a small outlier of the Middle Lias. The beds here are much hidden by Boulder Clay, but some brown shale and ironstone were exposed in draining the fields, which evidently belonged to this formation.*

South of Whitwell the beds are thrown up by a fault, and being covered by Boulder Clay, the outcrop is rather obscure, but it is again well exposed in the beck at the village of Crambe. Beyond the river Derwent the Middle Lias becomes very thin, and cannot be traced continuously; the only evidence that we were able to obtain of the rock being in Howsham Wood below Spy Hill, and in the little beck coming down from Leavening, where the characteristic fossils, *Rhynchonella tetrahedra*, *Cardium truncatum*, and *Ammonites spinatus*, were obtained.

South of this the Middle Lias thins out entirely; and, although the Lower Lias forms a very distinct outcrop, and the Upper Lias is seen at a few places, there is no evidence whatever of the beds between for a distance of nearly eight miles.

In the southern area, when the Middle Lias comes in again, the beds appear to have altered somewhat in character, and consist in the northern part of thin oolitic ironstone about three feet thick, which is seen at a few places cropping out beneath the Chalk; but further south the thickness increases to eight or nine feet, and contains beds of thin irregular flaggy limestone; further south still it is probably thicker, but as it passes beneath the level of the plain there is no means of knowing.

In Millington Dale near the Springs, immediately below the Red Chalk, there is a thin outcrop of sandstone and ironstone. containing *Belemnites*†; and on the brow of the hill south of Kildwick Percy Wold House there are fragments of an oolitic rock scattered about which are probably of this age. The evidence in neither of these cases is very good, although the fact of the upper part of the Lower Lias being seen at Warter brick-yard rather tends to show that the Middle Lias may exist near the base of the Chalk about here.

South of Nunburnholme the Middle Lias is seen in ditch sections near Partridge Hall, south of which the beds are thrown up by a fault, and do not again appear from beneath the Chalk till we get to Goodmanham, where ironstone fragments with *Pecten* are common at the base of the Chalk, although the bed at first is not thick enough to map. *Ammonites spinatus* was also obtained from here. To the south of Goodmanham the bed becomes more distinct, and may be traced round the sides of that valley, there

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* Messrs. Tate and Blake have mapped this as Oolite, but we could find no evidence for doing so, in fact the general structure of the surrounding country does not allow of such a supposition.

† Messrs. Tate and Blake mention the occurrence of these beds in Whitehill Dale [? Whitekeld Dale] *l.c.* p. 148.

being a section in the road on the south side of the railway which shows,*

	Ft.	In.
Ironstone	1	0
Grey clay	0	6
Ironstone	3	6
Clay		

From this point the outcrop is probably continuous, although not always seen; below Sancton it becomes very distinct, forming quite a terrace to the west of the village. At Cauldwell Spring the rock has rather an unusual appearance, being a dense blue oolitic limestone, which, on examination under a lens, seems to consist of brown and white oolitic grains cemented by iron. It is very probable that the rock here owes its dark colour to being less oxidized than in other places It is very fossiliferous, and contains *Ammonites spinatus*, *Pecten* (like *P. vimineus*), &c.

The following analysis of the ironstone from this place has been made by Mr. L. Gjers of Middlesborough:—

Protoxide of iron	24·70
Peroxide of iron	5·20
Protoxide of manganese	0·50
Silica	8·80
Alumina	7·85
Lime	20·50
Magnesia	4·00
Phosphoric Acid	0·60
Sulphur	0·90
Com. water	2·40
Carbonic Acid	24·50
	99·95
Loss by calcination	27·50
Metallic iron	22·80
Metallic iron in calcined stone	31·45

South of Sancton the outcrop is somewhat obscured by sands, but it is seen in the road at the boundary of the parish, opposite Newbald Sike, and at a few places on the west side of the road as far as Newbald. Above Hotham and North Cave it again forms a good feature and is well exposed, being cut into by the roads going up the bank east of these places. The rock here is largely made up of brown and grey crystalline limestone, and contains the following fossils,—*Rhynchonella tetrahedra*, *Terebratula punctata*, var. *Edwardsii*, *Avicula inæquivalvis*, *Pecten æquivalvis*, and *Lima*.

The railway at Everthorpe gives about the best section of these beds of any in the district. The strata here, which are lying very flat, are exposed in the cutting for a distance of over 200 yards, and consist of ferruginous flaggy limestone, with a very irregular top, much broken by large "pipes"; below are shales, the whole, including the soft beds at the bottom, having a thickness of about

* Compare Tate and Blake, The Yorkshire Lias, p. 143, where a list of characteristic fossils from this place is given.

nine feet.* South of here the outcrop curves round through the village of Everthorpe to Castle Farm† and South Cave Church, forming a good terrace to the west of the park. It crosses the lower end of the Fish Pond, being seen in the road below, and may be followed along the bank to Ellerker, where it crops out in the beck passing through the village; beyond this it gets below the level of the sands, but has been cut into by a ditch about three-quarters of a mile to the south, and was also met with in the boring near Brantingham Grange, of which the following particulars have been furnished by Mr. T. Allison of Guisbrough :—

Section of diamond drill boring near Mill Hill, between Elloughton and Brantingham Grange.

	FT.	IN.		
Soil and yellow sand	7	6		
Yellow clay	13	0		
Calcareous sandstone	2	0		
Blue Cave limestone	27	0		
Dark shale and calcareous bands	26	0		
Dark shale and calcareous bands	12	0		
Grey clay shale	14	0		
Brown siliceous stone	1	8		
Brown ferruginous stone	5	4	9	8
Blue ferruginous stone	2	8		
Blue shale	35	10		
Calcareous ferruginous band	0	7		
Shale with broken shells	2	6		
Calcareous ferruginous band	0	5	16	6
Dark clay shale	7	0		
Dark clay shale with calcareous ferruginous bands	6	0		
Dark clay shale	28	0		
Total	192	6		

The several subdivisions in this boring are somewhat doubtful, but it is probable that the alternating calcareous and ferruginous bands with beds of shale 16 ft. 6 in., should be referred to the Middle Lias.

From the neighbourhood of Ellerker the following fossils were obtained,—*Rhynchonella tetrahedra*, *Terebratula punctata*, var. *Edwardsii*, and *Belemnites breviformis*.

Comparative thickness of the Ironstone Series.

From the foregoing sections we see that the Ironstone Series as a whole increases in thickness towards the east, but that the individual seams of ironstone become thicker in the opposite direction. Thus at Hawsker there are about 100 feet of strata belonging to this series, while in Skelton Beck there are not more than about 80 feet, and further west at Eston the thickness is probably less than this, although there is no exposure in which

* Messrs. Keeping and Middlemiss, in describing this section, make the Middle Lias rather thicker, as they include the *capricornus* beds at the base. Geol. Mag., dec. ii., vol. x. p. 216.

† There are two places of this name. The text refers to the one at Cave Castle.

the exact amount can be estimated. At this latter place, however, in an average section of 28 feet 1 inch there is 20 feet 7 inches of ironstone; this becomes split up towards the east and south into numerous small seams and nodular bands, some of which die out altogether; so that on the coast, were it not for the numerous intermediate sections, it would be difficult to recognise to which seam many of these thin bands belong.

The gradual splitting up and thinning out of the ironstone seams is more clearly shown in the tables of comparative sections.

In the first of these, starting from Eston and following the beds along the northern outcrop, we observe how the good workable seams of ironstone gradually split up in passing eastwards, till on the coast they are represented by numerous thin bands which are of but little commercial importance.

In the second table also starting from Eston, which we have placed in the centre so as to show the variations the seams undergo both towards the south-east across the interior dales, and also to the south along the western escarpment, we notice in the first place the gradually dying out of the upper part of the ironstone or Main Seam, while the lower beds particularly the Pecten Seam and the Avicula Seam become very much stronger along the valley of the Esk, but split up entirely as they approach the coast into numerous thin bands which are difficult to correlate with the great seams of the interior.

In the second place following the seams to the south of Eston along the western escarpment, that is to the left in the table, we find that the principal seams are in many cases capable of being recognized for some distance, although the Pecten Seam soon disappears in this direction.

Another point of much interest in the development of the ironstone seams is the change which the Main Seam itself undergoes. Mr. Barrow, writing on this subject says, examining the beds in detail, the upper part of the Ironstone Series at Eston consists of the following parts:—

1. Top block, an impure ironstone, about three feet thick, used as a roof, and never mined at Eston. At the base of this is a band of iron pyrites with oolitic grains, which forms a well-marked horizon.
2. Main Seam proper. A blue oolitic ironstone, of almost uniform character throughout. *Am. spinatus*, the large *Pecten æquivalvis*, *&c.* which occur isolated. Thickness about 11 feet.
3. Black-hard, or mottled stone, a highly ferruginous shaly ironstone, full of shell masses. Of these the most common is the *Pecten æquivalvis*. In this bed, but not at Eston, we have also found *Am. spinatus*. In consequence of the profusion of the former fossil, we have called this the Pecten Seam; being, in fact, the bed worked at Grosmont.

This last shelly ironstone may be followed under Eston Hill in the main road that passes to Chaloner's Pit. But in its course, instead of being immediately under the Main Seam as at Eston, it is separated from the blue oolitic stone by a bed of shale three feet thick on the south side of the hill. Again, in the sections at Spa Wood and Kildale Mines, the shale parting is well seen, while it was proved in Lingdale Pit to be three feet thick. On

the coast at Staithes Nab the bands of shelly ironstone, with the masses of *Pecten*, are very clearly seen, as indeed are all the ironstone beds. There is three feet six inches of shale immediately above the Pecten Seam here. In the Upleatham and Skelton district the bed can be instantly recognised, and the evidence from all these exposures conclusively shows that this bed at the base of the Main Seam, or as we call it the Pecten Seam at Eston, is identical with the Pecten Seam at Grosmont. The latter being no part whatever of the Main Seam proper, as worked at every mine except Eston.

In tracing the Main Seam eastwards from Eston, where we have noticed that it has its maximum development, we find that it thins most slowly along a line drawn from Upsall pit and passing just south of Upleatham and Brotton to the coast. North of this line the seam thins at first slowly, then more rapidly as may be seen by comparing the sections at the south and north end of Huntcliff mine, where the thickness of the ironstone is 8 feet 3 inches and 6 feet 3 inches respectively. This is also noticeable in Upleatham mine; where there is 9 feet 6½ inches at the south end, but only 9 feet 8 inches at the north end.* South of this line the ironstone generally becomes slowly thinner until as we notice below a band of shale comes in, after which it thins very rapidly.

Towards the east the centre of the seam becomes harder and of a yellow colour. This portion which is inferior in quality to the rest of the seam is known as the dogger or hard band. Further south a band of shale also comes in which has to be picked out from the ironstone, and materially increases the cost of working. This shale band is very regular in its occurrence, and is found only to the south of a line passing through Waterfall Wood, Airy Hill, just north of South Skelton Shaft and Carlin How Shaft, where it is just visible, to the sea at Rockcliff. South of this line the Main Seam is split up, and rapidly deteriorates both in quality and quantity.† These changes are so extremely regular that the thickness of the ironstone at any point may be calculated from the nearest known sections.

* Compare also sections in the Geology of North Cleveland, pp. 25–29. (Geol. Survey Mem.)

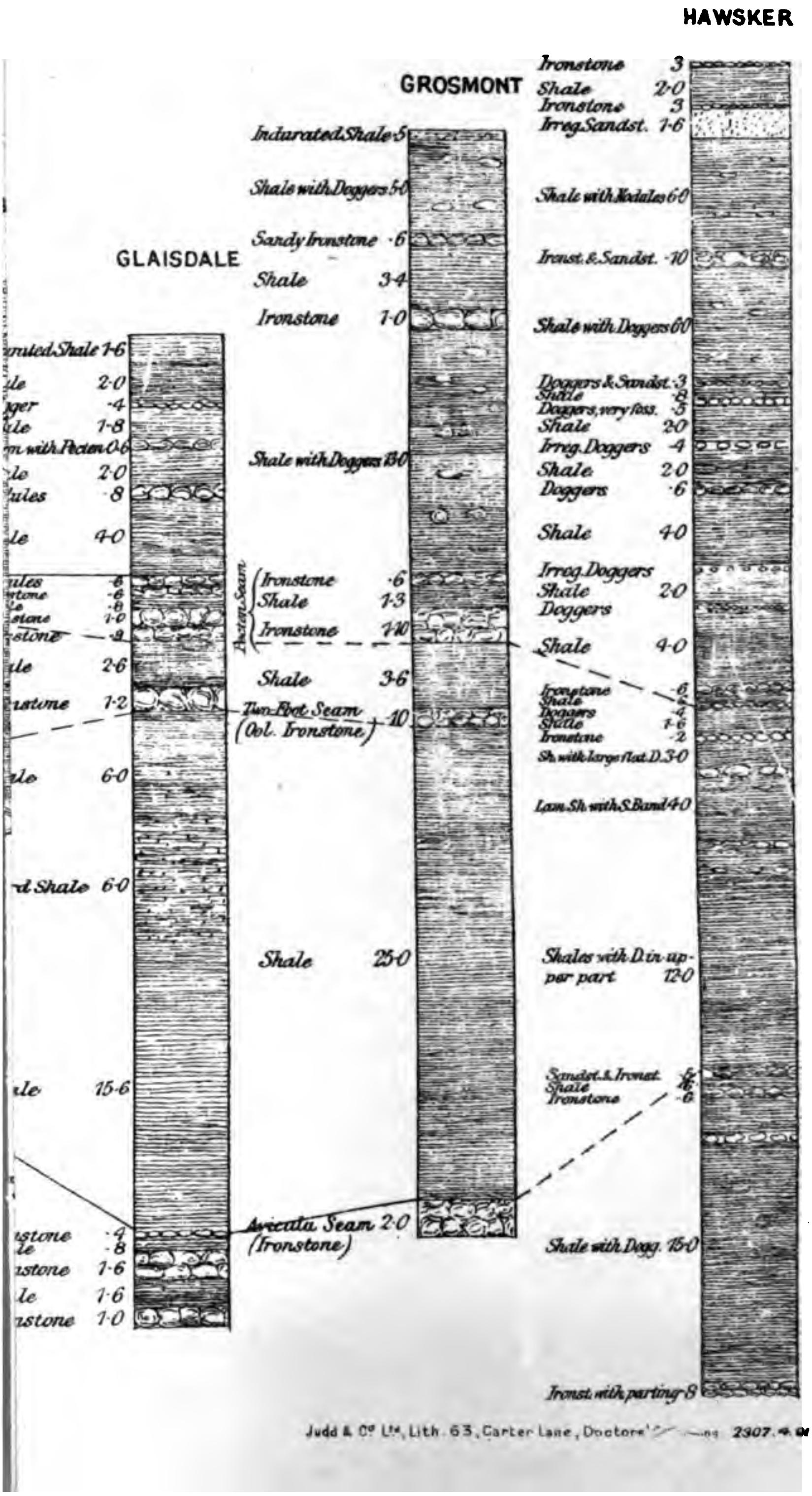
† A line somewhat similar to this is noticed by Steavenson, Journ. Iron and Steel Inst. 1874. Map.

ONE SEAM

rpment and

PLATE III

ss the interior dales ------S.E.



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CHAPTER IV.

THE LIAS (*continued*).

Upper Lias.

Account of the Zones in the Upper Lias, as they are exhibited in the Yorkshire Cliffs.

The Upper Lias consists of three distinct zones to which in some cases a fourth may be added, but this latter is hardly ever present; in fact it is only in the Peak cliffs on the coast that it has as yet been recognised, although clearer sections might reveal this zone at a few of the inland localities.*

These zones are characterized in descending order by the following ammonites. 1. The Jurensis Shale or Zone of *Ammonites jurensis*, Zieten. 2. The Alum Shale or Zone of *Ammonites communis*, Sow. 3. The Jet Shale or Zone of *Ammonites serpentinus*, Rein. 4. The Grey Shale or Zone of *Ammonites annulatus*, Sow.

The Zone of Ammonites annulatus.

Synonyms and Foreign Equivalents:—"Hard and compact alum shale," Young and Bird, Geol. Survey of the Yorksh. Coast, p. 136, 1822; "Soft alum shale," Phillips, Geol. of Yorksh., p. 97, 1829; "Soft shale" (lowest part of the Upper Lias), Williamson, Trans. Geol. Soc., ser. 2, vol v., p, 225, 1837; "The lowest bed of the upper shale," Hunton, Trans. Geol. Soc., ser. 2, vol. v., p. 217, 1837; "Grey shales, Zone of *Ammonites annulatus*," Tate and Blake, The Yorkshire Lias, p. 168, 1876. The shales comprising this zone are in most other districts either absent or inseparable from the rest of the Upper Lias; consequently a part of the synonomy is included in the other zones.

Messrs. Tate and Blake class this zone with the Middle Lias on account of the general facies of the fossils having a medio-liassic character, although the type ammonite itself is essentially an Upper Lias form. Palæontologically, no doubt there is a greater break between this zone and that of *Am. serpentinus* than at the top of the *spinatus*-beds; but petrologically these beds taken as a whole have more affinity with the Upper Lias, although in some cases the shales are very similar to those of the Ironstone Series.

These beds consist of compact grey shales, which when exposed to the weather easily crumble away, and thus form a hollow in which sections are frequently obscured by the débris of higher strata. These shales are interstratified with numerous nodular bands of earthy impure limestone, which, particularly towards the middle of the series, usually contain *Am. annulatus*. *Belemnites cylindricus* is also fairly plentiful, but with this exception the zone is remarkable for the scarcity of its fossils.

* The information in this chapter, where not otherwise acknowledged, is mainly taken from Mr. Barrow's description of these beds in the Memoirs of the Geological Survey relating to the district; and that referring to the inlying dales from Mr. Reid's account in the Explanation of Quarter-Sheet 96 N.E.

This zone is very constant both in character and thickness, the average being about 30 feet; when met with in borings the thickness often erroneously appears to be greater from the great similarity of these shales to the upper part of the *spinatus*-series.

At Peak the Grey Shale crops out on the shore immediately south of the fault, but it is always more or less covered by water, and also is much obscured by the loose blocks of sandstone which have fallen over it. It can be fairly well seen in Howedale gorge, but is rather inaccessible. The best sections on the coast are at Hawsker Bottoms; at Overdale Wyke, and along the shore below Goldsborough; on the east side of Runswick Bay; and at Brackenberry Wyke, where it rises in the cliff, and, passing inland to the back of Staithes, reappears again in Boulby Cliff, and in the railway cutting above Huntcliff. Inland these shales are well exposed at Hob Hill, and above the Ironstone Series at Upleatham, Eston, and Normanby.

Fossils from the Zone of Am. annulatus.

ECHINODERMATA.

Extracrinus britannicus, *Schlot.*

CRUSTACEA.

Bairdia dispersa, *Blake.*	Bairdia liassica, *Brodie.*

INSECTA.

Buprestites brachtoides, *Blake.*

BRACHIOPODA.

Rhynchonella Bouchardii ?, *Dav.*

LAMELLIBRANCHIATA.

Avicula inæquivalvis, *Sow.*	Goniomya hybrida, *Münster.*
—— papyria, *Quenst.*	Leda galathea, *d'Orb.*
Inoceramus substriatus, *Münster.*	Macrodon intermedius, *Simp.*
Limea acuticosta, *Münster.*	Modiola numismalis, *Oppel.*
Pecten æquivalvis, *Sow.*	—— scalprum ?, *Sow.*
—— substriatus, *Röm.*	Nucula cordata, *Goldf.*
Pinna spathulata ?, *Tate.*	Pholadomya ambigua, *Sow.*
Astarte striato-sulcata, *Röm.*	Pleuromya costata, *Y. & B.*
Cardium truncatum, *Sow.*	—— rotundata, *Ziet.*
Cypricardia cucullata, *Münster.*	Unicardium subglobosum ?, *Tate.*

SCAPHOPODA.

Dentalium elongatum, *Münster.*	Dentalium liassicum, *Moore.*

GASTEROPODA.

Actæonina ilminsterensis, *Moore.*	Chemnitzia semitecta, *Tate.*
Cerithium liassicum, *Moore.*	Eucyclus cingendus, *Tate.*
Chemnitzia acula, *Tate.*	Turbo aciculus ?, *Stoliczka.*
—— Blainvillei, *Münster.*	—— cyclostoma ?, *Benz.*

CEPHALOPODA.

Ammonites annulatus, *Sow.*	Belemnites breviformis, *Voltz.*
—— cornucopia, *Y. & B.*	—— cylindricus, *Simp.*
—— elegans, *Y. & B.*	—— latisulcatus, *Phil.*
—— margaritatus, *Mont.*	—— scabrosus, *Simp.*
—— semicelatus, *Simp.*	—— striolatus, *Phil.*

THE ZONE OF AMMONITES SERPENTINUS.

Synonyms and Foreign Equivalents:—"Sandsend Beds," Young and Bird, Geol. Survey of the Yorkshire Coast, p. 136, 1822; "Hard shale of the Upper Lias," Phillips, Geol. of Yorksh., p. 97, 1829; "Die Posidonien-schiefer" (part), Römer, Verst. Ool., p. 5, 1836; "Liasschiefer" (part) v. Buch, Jura Deutschl., Berlin Akad., 1837; "Jet Rock," Hunton, Trans. Geol. Soc., ser. 2, vol. v., p. 216, 1837; "Schistes bitumineux, ou schistes de Boll" (part), Marcou, Le Jura salinois, p. 53, 1848; "Die Schichten der *Posidonomya Bronni*" (part), Oppel., Juraformation, p. 197, 1856; "Communis-bed" (part), Wright, Quart. Journ. Geol. Soc., vol. xiv., p. 25, 1858; "Lias ε" (part), Quenstedt, Der Jura, p. 204, 1858; "Serpentinus-Beds," Judd, Geol. of Rutland (Geol. Survey Mem.), p. 79, 1875; "Jet-Rock Series, or Zone of *Ammonites serpentinus*," Tate and Blake, The Yorkshire Lias, p. 173, 1876; "Zone of *Harpoceras serpentinum*," Wright, Lias Ammonites, p. 116, 1879.

The shales comprising this zone, although they pass somewhat gradually into the *communis*-beds above, nevertheless, on the whole, form a marked contrast both to them and to the beds below; the change from the grey crumbling shales to these dark, dense, and finely laminated beds being very remarkable. Messrs. Tate and Blake, in their work on the Yorkshire Lias, draw the junction between the zones of *Am. communis* and *Am. serpentinus* some way down in these dark shales; but there does not appear to be any adequate reason for so doing, especially as Ammonites allied to *Am. serpentinus* occur considerably above the line drawn by them; and the general facies of the fauna throughout these dark shales is rather that of the serpentinus than the communis type. This being the case we are inclined to extend the zone to the double band of nodules containing *Am. ovatus*, which forms a conspicuous line at Saltwick, and appears to be on the horizon of the principal change in the character of the fossils. These shales, which have a thickness of about 90 feet, are well seen at Saltwick, where the following section has been measured:—

Section of the Zone of Ammonites serpentinus *in the neighbourhood of Saltwick.**

No.	Petrology.	Thickness. Ft. In.	Organic Remains.
1	Double line of pyritous doggers with masses of Belemnites, and exhibiting cone-in-cone structures.	0 10	*Am. ovatus, Belemnites dorsalis, Bel. subtenuis.*
2	Hard blue-black shales -	15 0	*Am. serpentinus, Inoceramus dubius.*
3	Red indurated band with pyritous lumps.	0 6	
4	Hard dark shale 12 ft.—15 ft.	13 6	

* The lower beds are usually covered by the water at Saltwick, so that the lower measurements are taken from the exposures at Hawsker and to the north of Sandsend.

	No.	Petrology.	Thickness. Ft. In.	Organic Remains.
	5	Line of scattered doggers.	—	
	6	Hard dark shales with great numbers of fossils 18 ft.—20 ft.	19 0	*Am. serpentinus, Am. heterophyllus, Am. gracilis, Bel. tubularis, Inoceramus dubius.*
	7	Line of pyritous doggers.	—	
	8	Hard dark shales, forming the shore at Saltwick Nab.	20 0	*Inoceramus dubius.*
Jet Rock.	9	Solid band of hard indurated shale, which weathers out on the shore into large tabular doggers. This bed forms the roof of the jet workings.	1 0	
Jet Rock.	10	Hard dark shales 4 ft. 6 in. —6 ft.	5 3	
Jet Rock.	11	Line of large irregular doggers, some distance apart.	—	
Jet Rock.	12	Shales with several rows of small doggers. Forms the lower part of the jet workings.	9 0	
Jet Rock.	13	Hard dark laminated shales.	8 0	*Am. elegans. Posidonomya Bronni.*
		Annulatus-shales below.		
		Average thickness -	92 1	

This division of the Upper Lias, from its being the source from whence all the hard jet has been obtained, is locally well known in Yorkshire. The workings have rendered the outcrop, both in the cliffs and along the inland escarpments, very conspicuous, and sections in this part of the zone are consequently very numerous.

These beds consist in the upper part of hard blue-black shale separated by indurated bands and lines of nodules into several well-marked horizons characterised by different species of Belemnites and other fossils. Below this are about 25 feet of hard compact bituminous shale with many rows of nodules in the upper part. These latter are the beds worked for jet, and consequently are generally known by the name of the Jet Rock.

The smaller nodules have generally only a pyritous skin or coat, the interior being a blue cement-stone having a powerful odour of mineral oil. At the top of the Jet Rock is a continuous band of doggers, which may be well seen at Saltwick, at low tides; they are sometimes as much as 15 feet in diameter, and very hard, being composed of sandy shale in long thin plates, cemented together by carbonate of lime and iron. This continuous dogger-

band forms the roof to all the workings for hard jet,* which occurs in greatest quantity for about 10 feet below this band.

The long line of breakers that can be seen at almost all tides from Black Nab to Saltwick is caused by the upper part of this rock, the lenticular doggers of calcareous and ferruginous shale being here very hard and of enormous size. At very low tides the breakers caused by this bed can be clearly seen from the top of the cliffs in the form of a curve stretching west till it is due north of the Old Abbey.

The most characteristic fossils of this zone are *Am. serpentinus* and *Inoceramus dubius*, in addition to which *Am. elegans*, *Am. heterophyllus*, *Am. gracilis*, and *Belemnites tubularis* are tolerably abundant; but what makes this zone especially interesting to the palæontologist are the large number of fish remains, particularly *Lepidotus semiserratus*, and also Saurians, which have been brought to light by the jet workings.

At Peak these shales are exposed on the shore just south of the fault, where the large doggers, which lie just above the workable beds, are very conspicuous. The series is, however, not very well seen here, being to a great extent covered up by the débris along the shore. From this point it is thrown up to immediately below the Peak Alum Works, where it has been extensively mined along the face of the hill. At Stoupe Brow it is covered by a thin coat of Boulder Clay, but it emerges further west, and has been much wrought in Howedale. Beyond this point its outcrop is completely hidden till it reaches the North Cheek, after which it soon appears in the face of the cliff, forming the cap-rock at Nigh and Far Jetticks. Its position in the cliff-face is marked by the terrace still left from where the Jet Shales have been dug away, till it reaches the shore, in consequence of the northerly dip, at Hawsker Bottoms.

North of this the outcrop is well marked by the line of breakers mentioned above.

At Saltwick, as we have stated, the Jet Shales are very clearly exposed, and their presence is indicated below the water by the line of breakers as far as the great fault at Whitby.

To the west of this, the Jet Rock occupies the foreshore from Sandsend Ness to Overdale, and keeping in the cliff for a few yards, again forms the scar as far as Loop Wyke. The jet has been largely mined along the foot of the cliff below Goldsborough, the caverns formed by these old workings having a very weird effect. Many ammonites and fish remains may be obtained from the beds in this district. Owing to the quantity of bitumen and pyrites in this rock, spontaneous combustion is often set up, the effects of which are well seen near Old Nab.

The Jet Rock keeps a little above high-water mark along the east side of Runswick Bay, descending to the foreshore at Hob

* For further particulars with regard to jet, *see* p. 455 *et seq.*

Hole. The next outcrop is at the north-west point of the Bay, where this bed forms the foreshore in front of the ruined ironworks. A fault throws the strata down to the west, so that these shales occupy the greater part of Rosedale Wyke, their base being at about high-water mark half-way between the Wyke and Old Nab. From this point the excavations in the face of the cliff show the position of the Jet Rock as far as Staithes, where it turns inland, and is lost sight of under the Boulder Clay. A small exposure of it occurs in the small stream in Well Dale, half-way between the mouth of the tunnel for the Grinkle Mine railway and Hinderwell village.

Jet has been extensively mined in the small dale in which is the entrance to Grinkle Mine, but beyond this, clay obscures the beds as far as the cliff face. With the exception of these last workings, the rock has not been mined along four miles of its outcrop, in consequence of the covering of Drift. In the cliff itself a small ledge has been produced, by digging away the bed between the Boulby Alum Works and the west end of Lofthouse Alum Works. About Hummersea banks, though its position is clear enough, it has not been mined, but on turning inland the outcrop again plunges under thick Drift, and is not seen till Huntcliff is reached. Masses of the Jet Shale testify to extensive old workings about the foot of Warsett Hill, but the southerly dip quickly takes the bed under Boulder Clay once more.

Inland the Jet shales are well seen in the outliers of Hob Hill, Upleatham, and Eston Hills, but there are no exposures along the main outcrop till we get to Slape Wath above Guisbrough. From thence westwards these beds are well exposed and have been worked at numerous places both along the escarpment and in the interior valleys, as we shall notice presently in detailing the general development of the Upper Lias.

Fossils from the Zone of Am. serpentinus.

PLANTÆ.

Pachyphyllum peregrinum, *Sternb.*

ECHINODERMATA.

Extracrinus britannicus, *Schlot.*
Extracrinus dichotomus ?, *M'Coy.*

LAMELLIBRANCHIATA.

Avicula substriata, *Ziet.*
Inoceramus dubius, *Sow.*
—— Simpsoni, *Tate.*
Pecten pumilus, *Lam.*
Posidonomya Bronni, *Voltz.*
Ceromya exarata, *Tate.*
Pleuromya bituminosa, *Tate.*
Tancredia dionvillensis, *Terquem.*

GASTEROPODA.

Euomphalus minutus, *Schüb.*
Natica buccinoides, *Y. & B.*

CEPHALOPODA.

Ammonites aalensis, *Ziet.*
—— bifrons ?, *Brug.*
—— cæcilia ?, *Rein.*
—— cornucopia, *Y. & B.*
—— crassus, *Y. & B.*
—— Desplacei, *d'Orb.*
—— elegans, *Y. & B.*
—— exaratus, *Y. & B.*
—— fonticulus, *Simp.*
—— gracilis, *Simp.*
—— heterophyllus, *Sow.*
—— latescens, *Simp.*
—— Levisoni, *Simp.*
—— ovatus, *Y. & B.*
—— serpentinus, *Rein.*
—— similis, *Simp.*
Belemnites acuminatus, *Simp.*
Belemnites breviformis, *Voltz.*
—— crossotelus, *Blake.*
—— dorsalis, *Phil.*
—— inæquistriatus, *Simp.*
—— lævis, *Simp.*
—— longisulcatus, *Voltz.*
—— striolatus, *Phil.*
—— subaduncatus, *Voltz.*
—— subtenuis, *Simp.*
—— tripartitus, *Schlot.*
—— tubularis, *Y. & B.*
—— Voltzii, *Phil.*
Beloteuthis Leckenbyi ?, *Blake.*
—— subcostatus, *Münster.*
Geoteuthis coriaceus, *Quenst.*
Nautilus astacoides, *Y. & B.*
Teudopsis cuspidatus, *Simp.*

PISCES.

Belonorhynchus acutus ?, *Ag.*
Dapedius ovalis ?, *Ag.*
Gyrosteus mirabilis, *Ag.*
Lepidotus pectinatus, *Egerton*
—— rugosus, *Ag.*
—— semiserratus, *Ag.*
Leptolepis saltviciensis, *Simp.*
Pachycormus curtus, *Ag.*
—— gracilis ?, *Ag.*
—— latirostris ?, *Ag.*
—— latus ?, *Ag.*
—— macropterus, *Ag.*
Ptycholepis bollensis, *Ag.*

REPTILIA.

Plesiosaurus longirostris, *Blake.*
Steneosaurus brevior, *Blake.*
Thaumatosaurus propinquus, *Blake.*

THE ZONE OF AMMONITES COMMUNIS.

Synonyms and Foreign Equivalents:—"The great bed of aluminous schistus, or alum-rock" (part), Young, Hist. of Whitby, p. 771, 1817; "Main bed of alum shale," Young and Bird, Geol. Survey of the Yorksh. Coast, p. 129, 1822; "Upper lias shale or mine," Phillips, Geol. of Yorksh., p. 97, 1829; "Die Posidonienschiefer" (part), "Monotiskalk," Römer, Verst. Ool., p. 5, 1836; "Liasschiefer" (part), v. Buch, Jura Dentschl., Berlin Akad., 1837; "Schistes bitumineux, ou schistes de Boll" (part), Marcou, Le Jura salinois, p. 53, 1848; "Die Schichten der *Posidonomya Bronni*" (part), Oppel, Juraformation, p. 197, 1856; "Communis-bed" (part), Wright, Quart. Journ. Geol. Soc., vol. xiv., p. 25, 1858; "Lias ε" (part), Quenstedt, Der Jura, p. 204, 1858; "Zone of *Ammonites communis*" (part), Wright, Ool. Asteroidea, Pal. Soc., p. 38, 1863; "Zone à *Am. bifrons*," Reynès, Géol. et Pal. Aveyron, p. 65, 1868; "Communis-Beds" and "*Leda ovum* Beds," Judd, Geol. of Rutland, Mem. Geol. Survey, p. 80, 1876; "Zone of *Harpoceras bifrons*" Wright, Lias Ammonites, p. 127, 1879.

This zone, like that just described, is also, from its former commercial importance, well known in Yorkshire; the shales of which it is composed having been very extensively worked for the manufacture of alum. These old workings, which are very numerous along the Coast and in the escarpment of the Cleveland Hills, have formed great scars in the hill sides in which the beds are even now well exposed; although of course the sections have, in course of time, become much obscured, and are not so satisfactory in a palæontological point of view as they formerly were.

The Alum Shale, which has a thickness of about 100 feet, consists of grey crumbling shale containing much disseminated pyrites

which causes a yellow incrustation on the weathered fragments. The shales have a very crisp feel which is very perceptible when walking over them, and is at once an indication of what beds we have before us.

The upper part of these shales contains lines of nodules, which were formerly used in the manufacture of cement, particularly in the neighbourhood of Sandsend, hence called the "Mulgrave Cement." The lower beds, which do not contain sulphate of alumina and consequently were not used in the alum industry, are darker and more bituminous, passing gradually into the *serpentinus*-beds below.

One of the most accessible exposures in these beds is that between Saltwick and Whitby; where, although it varies slightly in different parts, the general section is :—

Section of the Zone of Ammonites communis *at Saltwick.*

No.	Petrology.	Thickness.
		Ft. In.
1	Soft grey micaceous shale with cement-stone nodules in the upper 15 feet, containing *Am. bifrons*, *Am. communis*, *Am. crassus*, *Leda ovum*.	34 0
2	Lumpy calcareous band.	
3	Soft grey micaceous shales - - - - -	15 0
4	Hard nodular band ; not always present.	
5	Shales, similar to the above - - - - -	20 0
6	Indurated sandy band, becoming a distinct line of ironstone towards Whitby.	0 4 to 0 6
7	Shales, harder and darker - - -	18 0
	Double line of pyritous doggers.	
	Total - - -	87 6

The above section has been measured by several authors who differ somewhat in the various details. This arises from the fact that the beds do not preserve a uniform thickness, and some of the intervening bands disappear altogether: thus Prof. Phillips gives the section at Saltwick, while those of Messrs. Tate and Blake and Simpson appear to represent the beds nearer Whitby.

This zone is characterised by the great abundance of *Am. communis* and *Leda ovum* as well as by the great profusion of cephalopoda in general; it is also remarkable as the horizon of *Teleosaurus Chapmanni* and most of the other gigantic reptiles which the cliff sections and alum works have from time to time brought to light. In the south of England Saurian remains are found in the Lower Lias; but in this northern area, although

scattered fragments have been found here and there in the lower beds, Saurians do not appear to have found the conditions favourable for their existence till nearly the close of the Liassic period.

These shales are first seen at a few places between Blea Wyke and the Peak fault, but from the large amount of landslips and tumbled cliff the sections are of no great extent.

On the west side of the Peak fault there are constant exposures of these shales, especially in the great abandoned Alum Works at Peak and Brow. The best inland section, however, is probably that of Howdale, where almost the entire series may be examined and measured in detail. Beyond this point the Boulder Clay creeps up the hill, and the Alum Shale is not seen again till Pretty House is reached; where there is a section a few feet below the Dogger, but not actually showing the junction of the two. The shale has been turned out by rabbits in the woods and fields on the north side of Ramsdale Beck; while several exposures may be seen in the deep ditches about Park Hill. At Row there is a waterfall cutting into the Alum Shale to a depth of about 10 feet, the Dogger forming the top of it; and under the old Fylingdales churchyard wall the top of the shale crops out. At Bay Ness, and down the hill side, it can be plainly seen, as in many places there are scarcely three inches of soil. The whole of the series may be measured, though not examined, at Normanby Stye Batts; and from Maw Wyke to Whitby the base of the cliff and the scars consist of that portion of the Upper Lias.

After being depressed below sea-level by the great fault at Whitby Harbour, the Alum Shale rises again on the coast about a quarter of a mile before reaching East Row, where it is seen capped by the Dogger. It continues in the sloping hill for some distance, and is then covered by Boulder Clay, its outcrop in the steep bank on the south side of Mulgrave Woods not being seen. At Rock Head, however, is an old Alum Quarry, where the upper beds are well exposed, lower beds being seen in the sides of the small streams close by. Hell Scar, near Mulgrave Castle, is chiefly composed of Alum Shale, the capping of Oolites being very thin; from the base of this scar to the sea, the bed of the stream is composed of the hard shale below, a bank of pyritous doggers with *Am. ovatus* keeping a few feet up in the bank all the way.

From Sandsend to Kettleness, and Runswick Bay, the greater part of the cliff consists of these beds, but they are only accessible as a rule in the old Alum Works, such as Sandsend or Lythe, and the great Kettleness Alum Works. In the former, the cement nodules in the upper part of the Alum Shale were still worked in 1877, a considerable number of fossils being occasionally found in some of them. This is worthy of notice, as these nodules have almost disappeared further west at Kettleness, nor do they appear to have been met with in the tunnel, which has been driven through this part of the Upper Lias.

In the centre of Runswick Bay the Alum Shale has been denuded away and its place filled by Boulder Clay, but it reappears in the cliffs on the west side, and forms an encircling ring round the outlier of Hinderwell Fields. No part of the great mass of

Upper Lias shown on the Geological Survey Map south of Hinderwell, is actually visible, the old valley in which it occurs being completely filled with Drift; and it is not till reaching Rousby Beck under Low House, where there is a fine scar showing the upper part of the Alum Shale and its junction with the Oolite, that the Alum Shale is once more seen.

The next exposure of importance is in the cliff at the Boulby and Lofthouse Alum Works, where an enormous amount of these shales has been removed, and the Saurian remains were so numerous that one of the walks at Boulby House is edged with the vertebræ of these reptiles.

After passing the Lofthouse Alum Works, little or nothing is seen of the Alum Shale for a considerable distance, except the small exposure near the Liverton Mines. The rabbits have turned out small fragments of the shale on the north face of Warsett Hill, but, on the other two sides, the position of these beds is only shown by the feature which they make along the bank. The Hagg Alum Quarry near Saltburn, gives an interesting section, which shows the complete absence of the bands of cement nodules, and also the scarcity of fossils in this part of the area.

Further inland the Alum Shale is well exposed in the neighbourhood of Guisbrough and along the hills to the south, but to this we shall return again presently in the general description of the Upper Lias.

Fossils from the Zone of Am. communis.

CRUSTACEA.

Eryon Hartmanni, *Meyer.*

BRACHIOPODA.

Discina reflexa, *Sow.*
Lingula longo-viciensis, *Terquem.*

LAMELLIBRANCHIATA.

Avicula inæquivalvis, *Sow.*
—— substriata, *Ziet.*
Hinnites papyraceus, *Ziet.*
Inoceramus cinctus, *Münster.*
Ostrea subauricularis, *d'Orb.*
Pecten pumilus, *Lam.*
Gresslya donaciformis, *Phil.*
Gresslya rotundata ?, *Phil.*
Leda ovum, *Sow.*
Pleuromya æqualis ?, *Simp.*
—— elegans ?, *Phil.*
Tancredia dionvillensis?, *Terquem.*
Thracia glabra, *Ag.*
Trigonia literata, *Y. & B.*

GASTEROPODA.

Cerithium muricatum, var. quadrilineatum, *Röm.*

CEPHALOPODA.

Ammonites bifrons, *Brug.*
—— braunianus, *d'Orb.*
—— communis, *Sow.*
—— crassescens, *Simp.*
—— crassus, *Y. & B.*
—— Desplacei, *d'Orb.*
—— fibulatus, *Sow.*
—— heterophyllus, *Sow.*
—— Holandrei, *d'Orb.*
—— lythensis, *Y. & B.*
Ammonites ovatus, *Y. & B.*
—— subarmatus, *Y. & B.*
—— subcarinatus, *Y. & B.*
—— subconcavus, *Y. & B.*
Belemnites lævis, *Simp.*
—— levidensis, *Simp.*
—— pollex, *Simp.*
—— Voltzii, *Phil.*
—— vulgaris, *Y. & B.*
Nautilus astacoides, *Y. & B.*

PISCES.

Gyrosteus mirabilis, *Ag.*

REPTILIA.

Eretmosaurus macropterus, *Seeley.*
Ichthyosaurus acutirostris, *Owen.*
—— latifrons, *König.*
—— trigonodon, *Theodori* (crassimanus, *Blake*).
Plesiosaurus cœlospondylus ?, *Owen.*
—— homalospondylus, *Owen.*
Scaphognathus Purdoni, *Newton.*
Steneosaurus Chapmani, *König.*
Thaumatosaurus Cramptoni, *Carte & Baily.*
—— Zetlandi, *Phil.*

THE ZONE OF AMMONITES JURENSIS.

Synonyms and Foreign Equivalents:—"Sand of the Inferior Oolite" (part), Smith, and many of the older English authors; "Schwarzer Jura ζ, Jurensismergel," Quenstedt, Flozgeb, p. 539, 1843; "Marnes à *Trochus* ou de Pinperdu" (part), Marcou, Jura salinois, p. 54, 1846; "Die Schichten des *Ammonites jurensis*," Oppel, Juraformation, p. 228, 1856; "Cephalopoda-bed and Upper Lias Sands" (part), Wright, Quart. Journ. Geol. Soc., vol. xii., p. 292, 1856; "Ammonite Sands" (part), Hull, Country around Cheltenham, Mem. of the Geol. Survey, p. 25, 1857; "Jurensis-bed," Wright, Quart. Journ. Geol. Soc., vol. xiv., p. 25, 1857; "Lias ζ," Quenstedt, Der Jura, p. 276, 1858; "Zone of *Ammonites jurensis*" (part), Wright, Ool. Asteroidea, Pal. Soc., 1863; "Midford Sands" (part), Phillips, Geol. of Oxford, p. 118, 1871; "The Striatulus Beds," Hudleston, Proc. Geol. Assoc., vol. iii., p. 295, 1874; "Zone of *Lytoceras jurense*" (part), Wright, Lias Ammonites, p. 137, 1879.

Above the Alum Shale or zone of *Ammonites communis*, there are at Peak a considerable thickness of shales, which, although somewhat similar to those below in petrological character, have been found to contain a fauna that is sufficiently distinct from them to justify their being placed in a separate zone.

Although Prof. Williamson noticed the peculiarity of these shales in 1837,* Dr. Wright in 1859 was the first to correlate them with the corresponding beds in the South of England, and to point out that they were the equivalent of the Cephalopoda bed of that district.† Dr. Wright, however, as we shall see presently, when we come to treat of the Inferior Oolite, included higher beds in this zone; which, although possessing to a great extent the character of passage-beds, we have classed with the Oolites.‡

These shales, which from the characteristic ammonite are sometimes called the "Striatulus beds," have a thickness according to Messrs. Tate and Blake of about 80 feet; but owing to the great obscurity of the section, it is not easy to give anything like a correct estimate of how much should be assigned to this horizon.

* Trans. Geol. Soc., ser. 2, vol. v. p. 227.
† Quart. Journ. Geol. Soc., vol. xvi. pp. 3 and 4; Lias Ammonites (Palæontogr. Soc.), p. 144.
‡ Page 150. It is only the fifth or lowest of Dr. Wright's subdivisions that can really be said to belong to the Lias, and consequently to what we consider the Zone of *Am. jurensis*.

The only locality in which they have as yet been found is along the cliff between Blea Wyke and Peak, and even here they can only be examined at a few points. They are composed of grey sandy shales divided by three or four bands of nodules containing *Ammonites striatulus* and other fossils characteristic of the zone.

Of the fossils which occur in this zone a few pass up into the Oolites, but the majority of the species are either peculiar to these shales or are else Upper Lias forms; so that although they constitute in great measure a passage into the Inferior Oolite, they nevertheless have more affinity with the Lias.

The following section of these beds has been measured in the Peak cliffs:—

Section of the Striatulus-*beds or Zone of* Ammonites jurensis *at Peak.*

	Ft.	In.
Impure ironstone band; apparently corresponding with the lowest of the Blea Wyke Beds.		
Shales - - - - - - - -	9	0
Calcareous band.		
Shales - - - - - - - -	5	6
Calcareous band, cementstone.		
Shales - - - - - - - -	15	0
Calcareous band.		
Shales with nodular bands - - - -	25	0
Nodular band made up of small nodules.		
Shales with nodular and jetty bands, containing *Am. striatulus, Trigonia literata, Belemnites* -	12	0
Shales with *Am. variabilis*, base hidden by débris on the shore	12	0

The following fossils are recorded by Messrs. Tate and Blake from the zone of *Ammonites jurensis*:—

BRACHIOPODA.

Discina reflexa, *Sow.*
Rhynchonella jurensis ?, *Quenst.*
Waldheimia Lycetti, *Dav.*

LAMELLIBRANCHIATA.

Avicula inæquivalvis, *Sow.*
—— substriata, *Zeit.*
Lima toarcensis, *Desl.*
Ostrea subauricularis, *d'Orb.*
Pecten disciformis, *Schüb.*
—— pumilus, *Lam.*
Cardium substriatulum, *d'Orb.*
Gresslya abducta, *Phil.*
—— donaciformis, *Phil.*
Leda æquilatera, *Koch & Dunker.*
Trigonia literata, *Y. & B.*
Venus tenuis, *Koch & Dunker.*

SCAPHOPODA.

Dentalium elongatum, *Münster.*

GASTEROPODA.

Actæon Sedgvici, var. pullus, *L. & M.*
Cerithium armatum, *Goldf.*

CEPHALOPODA.

Ammonites comensis, *Von Buch.*
—— compactilis, *Simp.*
—— hircinus, *Schlot.*
—— insignis ?, *Schüb.*
—— jurensis, *Ziet.*
—— lectus, *Simp.*
Ammonites rudis ?, *Simp.*
—— striatulus, *Sow.*
—— variabilis, *d'Orb.*
Belemnites athleticus, *Simp.*
—— lævis, *Simp.*

Upper Lias.

General Account.

In the first part of this chapter we have given the petrological character of each distinct zone, it will now suffice to mention that as a whole they form a thick argillaceous or shaly series between the two great arenaceo-ferruginous deposits of the Inferior Oolite and the Middle Lias.

The following section which was measured in the cliffs south of Whitby gives a general idea of the character of these beds.

General section of the Upper Lias, measured between Whitby and Hawsker.

		Ft.	In.
Alum Shale.	Soft grey micaceous shale with cement-stone nodules in the upper part; containing *Am. bifrons, Am. communis, Am. crassus, Leda ovum, Gresslya donaciformis, Nautilus striatus, Belemnites vulgaris* - - - - -	34	0
	Lumpy calcareous band.		
	Soft grey micaceous shales - - - - -	15	0
	Hard nodular band, irregular.		
	Soft grey micaceous shales - - - - - -	20	0
	Indurated sandy band, sometimes forming a distinct line of ironstone.		
	Shales, somewhat harder and darker - - -	18	0
Jet Shales.	Double line of pyritous doggers with masses of Belemnites, and containing *Am. ovatus, Bel. dorsalis, Bel. subtenuis* - - - - - - - -	0	10
	Hard blue black shales. *Am. serpentinus, Inoceramus dubius*	15	0
	Red indurated band with pyritous lumps - -	0	6
	Hard dark shale - - - - 12 0 to	15	0
	Line of scattered doggers.		
	Hard dark shales with great numbers of fossils. *Am. serpentinus, Am. heterophyllus, Am. gracilis, Bel. tubularis, Inoceramus dubius* - - - 18 0 to	20	0
	Line of pyritous doggers.		
	Hard dark shales, forming the shore at Saltwick Nab -	20	0
	Solid band of hard indurated shale, which weathers out on the shore into large tabular doggers - -	1	0
	Hard dark shales - - - - - 4 6 to	6	0
	Line of large irregular doggers, some distance apart.		
	Shales with several rows of small doggers - - -	9	0
	Hard dark laminated shales. *Am. elegans, Posidonomya Bronni.* - - - - - - -	8	0
Grey Shales.	Soft grey shales with *Am. annulatus*, and *Bel. cylindricus* -	30	0
	Total Upper Lias - 205 10 to	212	4

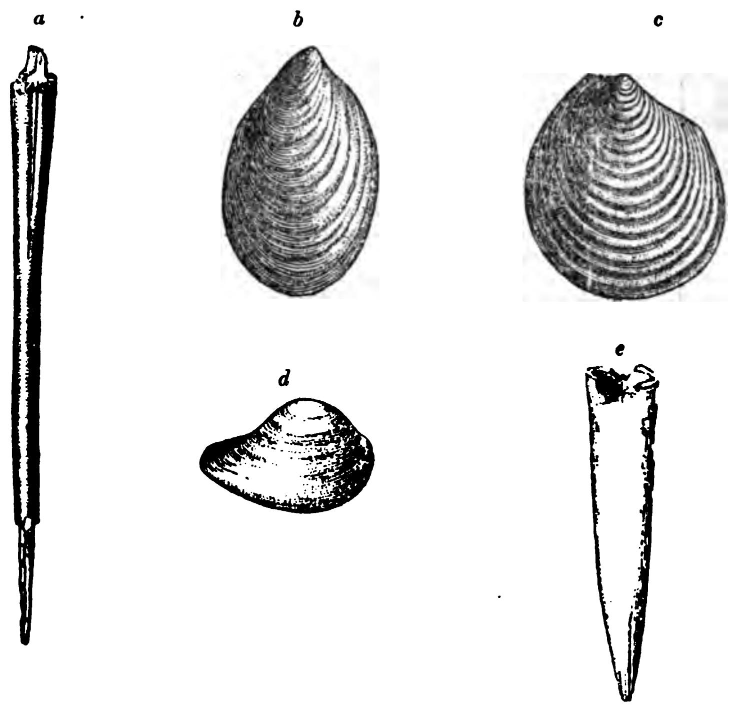
In the cliff and on the shore between Blea Wyke and the Peak fault the whole of the four zones comprised in the Upper Lias are present; but, owing to the large amount of fallen cliff, it is only a small portion of the beds that are really seen. Judging by the height of the base of the Oolites above the level of the sea, they must have a thickness of over 250 feet, but this is exceptional, the usual thickness of the whole Upper Lias being not more than 210 feet or thereabouts.

Beyond the Peak fault the Upper Lias curves round at the foot of the great amphitheatre of hills encircling Robin Hood Bay, the upper part being well exposed in the large excavations formed by the Peak and Brow Alum Works, while in Howedale Beck the whole of the series may be fairly seen.

On the north side of the bay the beds fall rapidly with the northerly dip, so that at Hawsker Bottoms the Grey Shale and the Jet Rock reach the level of the sea; and from thence northwards to Saltwick only the upper beds are exposed, although the hard shales of the Jet Rock are rendered evident for some distance by the line of breakers which may be observed at low-water between Black Nab and Whitby.

FIG. 6.

Upper Lias Fossils.



a, Belemnites tubularis, *Y. & B.* (after Phillips) $\frac{1}{3}$; *b*, Inoceramus dubius, *Sow.* (original); *c*, Posidonomya Bronni, *Voltz.* (after Goldfuss); *d*, Leda ovum, *Sow.* (original); *e*, Belemnites Voltzii, *Phil.* (after Phillips) $\frac{1}{2}$.

To the north of Whitby the Upper Lias appears again at Sandsend; from whence it occupies the cliff and a great part of the shore as far as Staithes, where from the gradual rise of the beds it finally leaves the shore, but comes in again in the upper part of the lofty cliffs of Boulby, and on the headland above Huntcliff. At this latter place the Upper Lias leaves the coast and turns inland along the northern face of the Cleveland Hills,

Throughout this range the Grey Shale at the base is rarely seen, owing to its lying in a hollow, which is generally filled with the débris of higher beds. These shales are however well known to the ironstone miners from the great difference in character between them and the rest of the Upper Lias.

The Jet Shales have been extensively worked on the outlier of Hob Hill, and in the northern face of the outliers of Upleatham and Eston Hills; but along the main escarpment there are no sections either in these beds or in the Alum Shale above till we reach Slape Wath just east of Guisbrough, where the Jet Shale has been worked for brickmaking, and the Alum Shale is exposed in the numerous old works of Rock Hole, Spa Wood, Cass Rock Quarry, and Belman Bank Quarry. Further along the escarpment to the south-west of Guisbrough as far as Roseberry Topping, the jet was much worked in old times, the so-called "Ancient British Settlements" being nothing but the remains of these pits.

In the neighbourhood of Kildale the lower part of the Upper Lias is completely hidden by Glacial deposits, but the different beds may be easily made out from the line of jet-holes, these shales having been worked on the north side of the valley, and also below Battersby Crag, and along the great Ingleby escarpment; while the Alum Shale is exposed in nearly every small stream and scar along the bank.

In Blue Bell Trough, the great scar immediately under Burton Head, all the subdivisions of the Upper Lias are well seen, and in Bilsdale down both sides of the valley an almost continuous line of jet pits marks the several horizons; but the clearest exposures are in Tripsdale, some distance above Hagg House, where the stream flows through a small gorge giving an almost complete section of the Upper Lias.

On the west side of Bilsdale, where the junction of the Lias and the Oolite is generally clearer than on the east, there are several good exposures, namely, in Stingamire Gill, in Fangdale Beck, and along the face of the escarpment between.

All the sections in this region show the great paucity of fossils in them when compared with similar beds on the coast and about Grosmont.

West of Bilsdale sections of the upper part of the Alum Shale are fairly numerous, as the water oozing from the Oolites causes landslips, which form great scars in the shales below; several of which occur in the face of Dromonby Moor.

In the nab-end of Carlton Bank there is an old alum quarry, in which many of the characteristic fossils may be found; but their relative scarceness is remarkable.

The position of the outcrop of the Alum Shale in the northern area, and, in fact, all along the escarpment, is too clear to need a detailed description, but there are a few interesting points to be noted. Of these the chief is the local erosion of the Upper Lias to a depth of nearly 100 feet at the south end of Cold Moor, in

Raisdale. The channel formed by this erosion passes through into Bilsdale, and is filled up by the basement beds of the Oolite, showing a clear local unconformity.

Another point of interest is the gradual thinning away of the Upper Lias, which, from being 200 feet thick at the north-east end of this area, diminishes to 160 feet at Swainby Mines, and to only 116 feet in the boring at Feliskirk; still further south this thinning continues, the Upper Lias being about 100 feet thick in the neighbourhood of Coxwold, and not more than about 80 feet near Crayke.

The Alum Shale does not crop out on the east side of the great faulted outlier of Borrowby, but on the west it is frequently seen; the sharp contact caused by the large fault between the Jet Shale, which has been mined, and the *Gryphæa arcuata* limestones of the Lower Lias, being very clear and distinct.

South of Silton, in the main escarpment, the Drift deposits creep up the hill, and in places entirely obscure the outcrop of the Upper Lias, the first clear exposure being on the hill side above Kepwick. In the pretty amphitheatre of Cowesby the Drift rises well on to the Oolitic sandstone, but some sections are visible in the little pass between that village and Kirkby Knowle, as well as at intervals in the hill to the west.

The Alum Shale is seen again about Knowle Hill; in the bank just above the village of Feliskirk; and in the sides of Mire Beck, near Thirlby; but there are not many exposures in this neighbourhood.

On the north side of Hood Hill laminated shales are exposed just below the base of the Oolites, which must be near the top of the formation, and at Osgodby Hall shales are also seen, which cannot be far from the base; the upper portion of these shales is again seen round the Oolitic outlier at Stockings House, and in the road between here and Kilburn, but the best section about here is just west of Low Kilburn, where the Jet Shales have been worked, and show these beds dipping at rather a high angle slightly to the north of east. About 600 yards south of this point the beds are cut by the great Coxwold north fault, by which they are shifted from 3 to 5 miles to the west; so that their next outcrop is about Highfield House, the well of which is sunk into Upper Lias shale, which might be seen a few years since close to the well; and a little north-west of the house the shale has been turned up in draining. The Jet Shales are exposed in the railway cutting south of Sessay Station, where the platy shale, in which Messrs. Tate and Blake record the presence of *Am. elegans*, is seen.

South of Coxwold the Upper Lias comes in again at Newburgh Park, and may be easily followed along the escarpment to the south-west, where it forms the clayey slopes between the features of the Middle Lias and the base of the Oolites. In the lane above Husthwaite these shales are exposed, and have been penetrated in a well at Gibbet Hill just above to a depth of

40 feet. By the Husthwaite fault they are depressed, so that they crop out in the low ground north of Providence Hill, and crossing the neck of alluvium are seen in the railway cutting at Thormanby Hill, where they contain *Inoceramus dubius* and a small *Ammonite*, and afford about the best section in the district. South of this they curve round with the base of the Oolite to the south of Oulston and Brandsby, but keeping in the low ground at the foot of the hill they are entirely concealed by Boulder Clay as far as the latter village.

In the neighbourhood of Easingwold, and thence along the range of low hills to Stillington, there are several small outliers of Upper Lias; which, although not very well exposed, are rendered evident from the position of the harder beds below. These are just above the town at Easingwold, at Howe Hill near Hanover House, at Crayke Hill, and between the large faults just east of Stillington.

At Brandsby the beds are elevated by a large fault, so that the Upper Lias crops out well up in the bank below the Oolite escarpment, and its course is very clear thence along this range of hills by Terrington, Mowthorpe, Stittenham, and Whitwell, to the Derwent at Crambe. It runs up this valley as far as Castle Howard Station, there being a good section in these shales opposite the weir at Kirkham Abbey.

On the further side of the Derwent these beds are continued beneath the Oolite; but no sections occur in them, except in Leavening Beck, where dark shales are seen, containing *Ammonites serpentinus*, and in Acklam Beck, where just below a waterfall the Jet shales appear.

In the neighbourhood of Kirkby Underdale the only exposures of these beds are in the vale east of Hanging Grimston, and at the head of the dale east of the village, where dark shale with *Inoceramus dubius* is seen immediately below the Cretaceous beds.* The outcrop about here is exceedingly obscure, and can only be mapped from the general appearance of the ground. It is possible that on the outlying hill of Oolite these beds are wanting through the thinning of that formation, or there may be a narrow band of the Upper Lias Shales round the hill. It does not seem that any system of faulting will account for the structure of this hill; nor is there any need to suppose an unconformity. To the south of Garrowby the Lias is certainly overlapped by newer formations, as we obtain Lower Lias beds close up under the Chalk at Bishop Wilton; the Oolites again come thinly in for a small space at Givendale, and there apparently overlie the Lower Lias.

Near Nunburnholme, judging by the space between the Middle Lias and the Chalk, it is probable that a small patch of Upper Lias shale peeps out from beneath that formation at Partridge Hall, but the bed is not seen.

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* I am indebted to my friend Prof. J. F. Blake (who has found Jet-rock *Ammonites* in these shales) for pointing out this locality to me.

South of Market Weighton the Upper Lias comes in again, and may be traced continuously almost to the Humber, although there are very few exposures. In this region it is very thin, and appears to consist principally of the *serpentinus*-beds, there being little evidence of the other horizons. It is probable that the several zones of the Upper Lias, which are so remarkably developed in North Yorkshire, south of the overlap, become to a certain extent blended and approach so close together that their fossils in most cases cannot be separated. Dr. Wright states* that the Upper Lias thins out altogether in South Yorkshire, but this is not the case; neither is there any evidence of its absence beyond what can be accounted for by the overlap of the Cretaceous beds.

The Upper Lias in this district first appears to the south of Sancton, where there is a strip of clayey ground between the Middle Lias and the Oolites, which must represent these shales; but they are not seen till south of the village, where, opposite Newbald Sike, is an old clay-pit in which they have been worked. A well here, just at the outcrop of the Red Chalk, is said to be 60 feet deep, and to have gone through 12 feet of limestone at the bottom. This, if it is to be relied upon, would give about 40 feet for the Upper Lias, and it cannot be any more, if so much, at this place.

To the south of this the clays are still very indistinctly seen, but may be followed by the line of slightly heavier ground they make between the other beds.

In Drewton Beck and in the road at Everthorpe a little clay is seen, but it is not till we reach Ellerker that anything like a good section is obtained. In the beck at this village the Middle Lias, as mentioned above, is seen; and above this, at the eastern end, just below the mill, there are dark laminated shales, which may be followed to the base of the Oolite. This being only a ditch section it is difficult to estimate the thickness, but it will probably be between 20 and 30 feet.

In a limestone quarry, about 700 yards to the south, these beds were reached in a trial-shaft for ironstone, and a large quantity of the shale with *Ammonites serpentinus* was turned out.

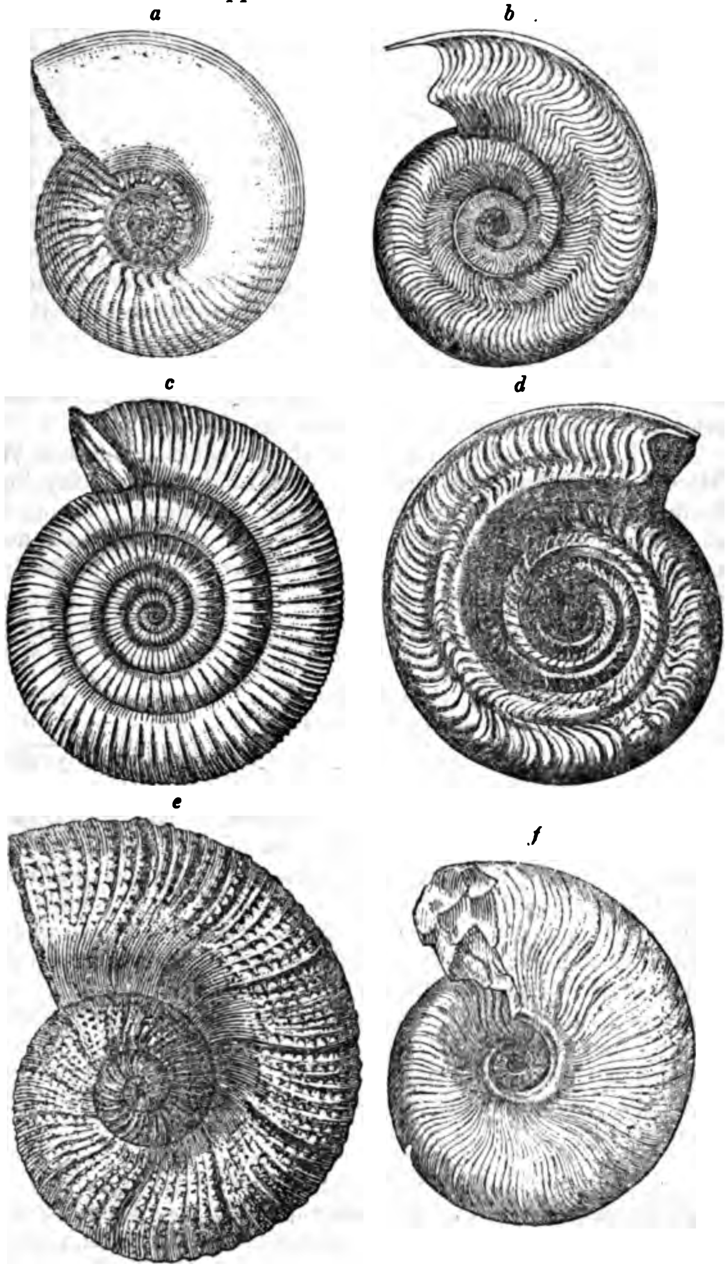
The following is the account of this shaft, furnished by Mr. Allison:—

	Ft.	In.
Calcareous soil - - - - - - -	1	0
Blue Cave limestone - - - - - -	18	0
Blue marl - - - - - - -	8	0
Yellow calcareous marl - - - - - -	3	6
Blue shale with nodules, *Ammonites serpentinus* abundant	7	0
Total - - - - -	37	6

* Monograph of the Lias Ammonites, Palæont. Soc., 1879, p. 114.

FIG. 7.

Upper Lias Ammonites.



a, Ammonites insignis, *Schüb* (after d'Orbigny) ¼; *b*, Ammonites serpentinus, *Rein.* (after d'Orbigny) ¼; *c*, Ammonites communis, *Sow.* (after Wright) ⅓; *d*, Ammonites bifrons, *Brug.* (after Wright) ⅓; *e*, Ammonites cornucopia, *Y. & B.* (after d'Orbigny) ⅔; *f*, Ammonites elegans, *Y. & B.* (after Wright) ½.

The wellsinker's account slightly differs, but agrees better with the beck section at Ellerker. It was—

		Ft.	In.
Limestone	- - - - - -	14	0
Hard stone	- - - - - -	2	0
Clay	- - - - - - -	4	0
Stone	- - - - - - -	3	0
Clay	- - - - - - -	6	0
Hard stone	- - - - - -	1	0
Black shale	- - - - - -	6	0
Total	- - - -	36	0

From this latter account it would appear that the "Stone 3 ft." is the Hydraulic Limestone, and the "Hard Stone 1 ft." the base of the Oolites.

About here the outcrop of the Lias sinks beneath the sands, and is not again seen, although it has been reached in the several trial-holes for ironstone between here and Brough.

At the point where the footpath to Ellerker crosses Whin Moor Lane, a shaft was sunk 17 feet in sand and blue clay, but no further particulars of the strata were kept, although, judging from the outcrop of Middle Lias ironstone near here, it must have nearly gone through the Upper Lias Shale; as also they probably did in the next shaft, which is 400 yards to the south, and gave—

		Ft.	In.
Sandy soil	- - - - - - -	3	0
Stony clay	- - - - - - -	1	0
Bottom part of Blue Cave limestone	- - -	1	6
Blue shale with nodules of cement stone	- -	17	0
Total	- - - -	22	6

In this section the "Blue Cave Limestone" will have been the basement bed of the Oolites, as the site of the shaft is certainly below the base of the Cave Limestone, and very near the base of the Oolites altogether.

The diamond boring near Brantingham Grange gives 35 ft. 10 in. of blue shale below the Oolite, if we are right in this interpretation of the section.* In Brough a boring at the back of he Railway Hotel is said to have reached "Sandstone" at 90 ft., while one at the Station is 18 ft. in clay, and then "Greystone," and one at Castle Hill is 40 ft. to "Stone," but there is so much discrepancy about these Brough borings that they are of little value.

Inliers of the Upper Lias.

In Eskdale there is a large inlier of the Upper Lias, extending from nearly a mile east of Sleights as far as Glaisdale, up which dale, owing to the strong northerly dip, the outcrop is continued, as well as in the smaller valleys of Egton Grange, the Murk Esk, and Iburndale.

* Page 122.

At the eastern end of this inlier the Grey Shale and Jet Rock are exposed in a few obscure sections near Littlebeck and Sleights, the latter having been worked below the Alum Works in Eskdale, and in Iburndale. The Alum Shale is only seen at one place on the north side of the Esk, namely, in the small stream coming down from Aislaby, where about 50 feet are exposed. On the south side there are several sections, the best of which are in Littlebeck Alum Works, in the banks of the stream below, in the neighbourhood of Falling Force, and at Thorn Hill Alum Works in Iburndale; as well as at the Alum Works on the brow above Sleights.

About Grosmont all the subdivisions of the Upper Lias are seen, the Grey Shale being exposed near the junction of the Esk and Murk Esk, and in the railway cutting just south of the tunnel; while the Jet Rock and the Alum Shale are seen further up the Murk Esk.

Above Egton and in Egton Grange the junction of the Jet Rock and Alum Shale is well exposed. A section in the latter valley at the northern end of Park Hole Wood shows:—

		FEET.
Alum Shale.	Shale with yellow edges - - - about	40
	Shale with a few lines of doggers, the upper ones cement stones, the lower more pyritous - -	18
Jet Rock.	Harder shale and small very tough pyritous doggers with *Inoceramus dubius*. One dogger was formed round a bone to which a number of *Am. gracilis?* adhered - - - - - -	2
	Total - - - - - -	60

Some of the best sections of the Alum Shale can be examined in the scars of the Esk and Glaisdale Beck, between Egton Bridge and West Arnecliffe, more particularly at Snowdon Nab, where the soft yellow-edged shale with *Leda ovum* forms a small scar.

In Glaisdale the Upper Lias is everywhere hidden by Boulder Clay, but there are sections in West Arnecliffe Wood which show 10 feet of soft grey shale with earthy doggers containing the characteristic *Ammonites annulatus*, and the Jet shale with *Ammonites gracilis*.

In Fryup Dale the Upper Lias is not well seen, but the Jet Rock has been quarried at Round Hill, while the rapid denudation at the head of Great Fryup has caused many large scars in which the upper beds are exposed.

In Danby Dale the Jet Rock has only been mined near Smallwoods House, but in Westerdale and Basedale the workings are very extensive, so that the outcrop can be accurately traced for long distances. In these dales there are numerous small exposures of the upper part of the Lias, but the lower beds are not seen except in Basedale, where the Grey Shale with *Am. annulatus* is found at two points; on the north side of the gill near Basedale Abbey, and again half a mile further south, but only in the latter case is there a good exposure.

In Bransdale, Farndale, and Rosedale, the three divisions of the Upper Lias are fairly distinct, the workings of the Jet Rock having been very extensive, but there are no sections which are continuous enough to measure. There is, however, a very good exposure of the middle portion of the Alum Shale in Cat Nab Scar at the head of Rosedale.

Besides the inliers of the great dales there are two places where the Oolites are cut through, exhibiting quite the upper beds of the Lias. The first of these occurs on Snilesworth Moor, there being several small patches of the Alum Shale in the higher part of the river Rye and its tributary Arns Gill. The other is in the centre of the Howardian Hills near Wiganthorpe. There is no real section of the Lias here, but its presence is proved by the boggy ground below the outcrop of the Dogger, which is brought up behind the large east and west fault.

CHAPTER V.

THE LOWER OOLITES.

General Remarks.

One of the most remarkable circumstances in the study of the English Jurassic rocks is the striking difference both in lithological and palæontological character between these strata as they occur on the coast of Dorset and their development in Yorkshire. Prof. Judd in writing on this subject says, "No fact in connection with the English Jurassic strata is of more striking character and significance than the wonderful differences between the sections displayed in the typical localities of the south-west of England, and those of the north-east of Yorkshire. The more thoroughly and minutely the rocks in these two districts are studied, the more striking do the discrepancies between the several members of the series appear; these differences being equally marked alike in regard to their thickness, their petrological character, and the distribution of their organic remains.

"It was by the careful study of the Oolites in the south-west of England that the accepted classification of the Jurassic system was first arrived at; but it was in Yorkshire that this classification, and the principle on which it was founded (that of the identification of strata by their organic remains) were submitted to a crucial test. Never had a new theory to pass through a severer ordeal than when the conclusions, arrived at from the study of the alternations of the limestones, sands, and clays, of the Bath district, were first applied to the elucidation of the massive coal-bearing sandstones and shales of the Moorlands of the north-east of Yorkshire; and never, certainly, did a theory come out of such trial more triumphantly, or with stronger proofs of its general soundness and great capabilities, than did this."*

Great as this difference is throughout the whole series of these beds, it is nowhere more marked than in the subdivision of the Lower Oolites. In the south of England these beds consist almost wholly of sediments deposited under marine conditions; although in the south of England the Stonesfield Slate and Forest Marble, and in the Midland counties, the Lower and Upper Estuarine Series, to a certain extent show the presence of neighbouring land. In Yorkshire it is just the opposite, in this area the Lower Oolites are composed mainly of a vast series of estuarine and freshwater beds which are separated into three or four distinct groups by thin marine bands. These beds, which in

* Memoirs of the Geological Survey. Geology of Rutland, pp. 1, 2.

their general physical conditions represent an Oolitic coalfield, are very similar to the poorer Coal Measures and Millstone Grit rocks of the western part of the county, containing thin irregular bands of coal with underclays, and a large number of land and marsh plants; but, although the sandstones and shales of the Lower Oolites so much resemble in lithological character those of the Upper Carboniferous rocks, an examination of the species of these plants shows that they are of a very different age; for, of about 50 species which have been obtained from the Oolites, not one occurs in the true Coal Measures.

These shaly and arenaceous strata are thickest to the north and west; from which direction the sediment of which they are composed appears to have been derived. Towards the south they become much thinner; and the calcareous bands, which as a rule are thin and unimportant in the north-west, become much thicker, some of them developing into important beds of limestone. This subject, however, will be dealt upon at greater length in the chapter on the ancient physical geography.

The Lower Oolite formation of the Yorkshire basin consists, as we have said, of three or four groups of estuarine strata separated by limestones or thin calcareous beds which have been formed under marine or littoral conditions. As some of these latter beds are very irregular and occasionally thin out altogether, it is not possible throughout the whole area to retain the several divisions of the estuarine beds, and they become blended from the disappearance of these marine bands. Thus the Millepore Bed is not known along the northern outcrop, while the Grey Limestone is absent in the extreme south.

The complete series of the Lower Oolites is as follows:—

Cornbrash.
Upper Estuarine Series.
Grey Limestone Series.
Middle Estuarine Series.
Millepore Bed.
Lower Estuarine Series with Eller Beck Bed or Hydraulic Limestone.
Dogger.

But one or other of these beds is nearly always absent, so that the section stands thus in the north and south respectively:—

South.	*North.*
Estuarine Series.	Cornbrash
Millepore Bed.	Upper Estuarine Series.
Estuarine Series (probably absent in the extreme south of the county).	Grey Limestone Series.
Hydraulic Limestone.	Estuarine Series.
Estuarine Series.	Eller Beck Bed.
Dogger (occasional).	Estuarine Series.
	Dogger.

Blea Wyke Beds.

The basement beds of the Lower Oolite consist of two portions—the Dogger proper, and the Sands below the Dogger. These latter, which are better known as the "Blea Wyke Beds" from their fine exposure at that place, constitute a sort of passage from the Lias into the Oolite.

Synonyms and Foreign Equivalents,—"Sands of the Inferior Oolite," Smith, De la Beche, Conybeare, and other English authors; "Conchiferous (dogger) series, analogous to the inferior oolite of Bath" (lower part), Phillips, Geol. of Yorksh., p. 91, 1829; "Inferior Oolite" (lower part), Williamson, Trans. Geol. Soc., sec. 2, vol. v., p. 227, 1837; "Untere Lage der Opalinus Thone mit *Am. torulosus*," Quenst., Flözgeb, Würtemberg, p. 284, 1843; "10e étage, Bajocien (pars inf.)," d'Orbigny, Cours élément. de Paléontologie, p. 477, 1849; "Zone des *Am. torulosus*," Oppel, Juraformation, p. 306, 1856; "Cephalopoda-bed and Upper Lias Sands," Wright, Quart. Journ. Geol. Soc., vol. xii, p. 292, 1856, and vol. xvi., p. 3, 1860; "Marnes d'Aresche, et Marnes de Pinperdu" (pars sup.), Marcou, Les Roches du Jura, p. 119, 1857; "Ammonite Sands" (part), Hull, The Geology of the Country around Cheltenham, Geol. Survey Mem., p. 25, 1857; "Cynocephala stage," Lycett, Cotteswold Hills, p. 16, 1857; "Torulosusschicht, Brauner Jura α," Quenstedt, Der Jura, p. 302, 1858; "Midford Sands" (part), Phillips, Geol. of Oxford and the Valley of the Thames, p. 118, 1871; "Grey and yellow sands" beneath the Dogger, Hudleston, Proc. Geol. Assoc. vol. iii., p. 295, 1874; "Blea Wyke Beds," Tate and Blake, The Yorkshire Lias, p. 19, 1876; "Zone of *Lytoceras jurense*" (upper part) and "Zone of *Harpoceras opalinum*," Wright, Lias. Am., pp. 144, 149, 1879; "The Dogger" (lower part), Strangways and Barrow, The Geology of the Country between Whitby and Scarborough, Geol. Survey Mem., p. 26, 1882.

These beds, as will be seen from the following comparative table, have been variously classed by different authors. Prof. Phillips considered them to be partly the equivalent of the Inferior Oolite and partly of the Midford Sands; Dr. Wright classed them with the Lias; Mr. Hudleston considered them a passage between the Lias and the Inferior Oolite; Messrs. Tate and Blake placed them with the Inferior Oolite. The thick line in the table shows the base of the Oolite as drawn by different authors:—

Comparative Table of the **Blea Wyke Beds**, showing the position of the **Junction** between the **Lias** and **Oolite** as drawn by different Authors.

Phillips, 1829, Revised 1875.	Wright, 1859.	Hudleston, 1874, 1885.	Tate and Blake, 1876.	Geological Survey, 1882.	
Yellow sandstone with fossils in nests and bands, and layers of pebbles, *Nerinæa*, &c., 30 ft. 0 in.	1. Reddish sand-rock unfossilferous, "Dogger," 10ft. 0in.	Thin ferruginous beds with a gritty texture, 7 ft. 0 in.	Higher beds of Inferior Oolite.	I. Hard, red, ferruginous sandstone with ferruginous nests, 10 ft. 0 in.	The Dogger.
	2. Fossiliferous seam with *Nerinæa*, &c., 1 ft. 0 in.	*Nerinæa* bed, 1 ft. 6 in.		II. Ferruginous band with *Nerinæa*, &c., 1 ft. 6 in.	
	3. Ferruginous sandstone, 8 ft. 0 in.	Sandstone with two beds of nodules, 24 ft. 6 in.		III. Greenish dogger sandstone with pebbles, 25 ft. 0 in.	
	4. Ferruginous sandstone with fossils, 5 ft. 0 in.				
	5. Yellow sandstone with pebbles, 5 ft. 0 in.		Yellowish sandstone with *Monotis*, 5 ft. 0 in.		
Bands of fossils, 3 ft. 0 in.	1. Dark friable shale with ironstone bands at base. *Terebratula*, &c., 1 ft. 6 in.*	Shale, 1 ft. 0 in.	Dark friable shale and ironstone, 1 ft. 6 in.†	IV. Ferruginous shaly bed, 1 ft. 2in.	The Yellow Beds.
		Chocolate-coloured rock with *Terebratula*, 3 ft. 0 in.		V. Brown sandstone with *Terebratula*, 2 ft. 0 in.	
Yellow sandstone, 20 ft. 0 in.	2. Yellow sandstone with *Am. insignis*, 20 ft. 0 in.	Yellow sands, 13 ft. 0 in.	Yellow sandstone 20 ft. 0 in.	VI. Soft brown sandstone with *Belemnites*, 25 ft. 0 in.	
		Greyhearted sands, 10 ft. 0 in.			
Grey sandstone with *Serpulæ*, &c. in four beds. (ft. in.) 6 0; 5 6; 5 0; 3 0	3. *Serpula* bed in two divisions, 10 ft. 0 in.	Grey sands, including the *Serpula* bed and *Lingula* bed, 26 ft. 0 in.	*Serpula* bed, 10 ft. 0 in.	VII. *Serpula* bed, 10 ft. 0 in.	The Grey Beds.
Grey sandstone, passing to Lias.	4. Grey sandstone with *Lingula Beanii*.		*Lingula* bed, 20 ft. 0 in.	VIII. Grey shaly sandstone with *Belemnites*, *Lingula*, &c., 25 ft. 0 in.	
				IX. Soft grey shale with *Lingula* at base, 7 ft. 0 in.	
	Argillaceous nodules with *Am. jurensis*.	Striatulus beds‡	Shales with layers of nodules, 70 ft. 0 in.	X. Dark shale with ironstone nodules.	The Lias.
	Alum shale.	Highly aluminous rock with *Nucula ovum*.	Alum shale.	Shales with *Leda ovum*.	

* *Opalinus* zone, Wright. Lias Am., p. 149.
† Error. Messrs. Tate and Blake have taken Dr. Wright's measurements without verifying them.
‡ In 1874 Mr. Hudleston appears to have included these beds with the Oolite, but in the Report to the International Geological Congress, 1885, the line is drawn as above.

Referring to Dr. Wright's opinion on this subject, Messrs. Tate and Blake point out that on palæontological grounds the beds above the *Striatulus* shales should be included with the Oolite and not with Lias. After discussing the evidence afforded by the Ammonites which are nearly allied to *Am. Murchisonæ*, and may be easily confounded with one another, they say, "On the whole, the evidence of the Ammonites amounts to this, that a certain family of them (and we may include *Am. insignis* in the category) began their existence before the great number of other Mollusca that came to be associated with them in Oolitic times; and if we were guided by this alone, it would be rather to lower the line of junction beneath the shales with *Am. striatulus* than to raise it any further.

"Again, with reference to the Liassic Belemnites, *B. compressus* and *B. irregularis* are said to occur in these disputed beds; the presence, however, of the latter is not confirmed by Phillips in his Monograph on the British Belemnites; and he makes the so-called *B. compressus* a distinct species under the name of *B. inornatus*, separated by the absence of any ventral groove. Of the remaining fossils *Terebratula trilineata, Rhynchonella cynocephala, Gervillia Hartmanni, Pholadomya fidicula* are characteristic species of the Oolite here and everywhere. *Lingula Beanii* is nowhere found in the Upper Lias; *Vermetus compressus, Serpula deplexa* and *Glyphæa Birdi* are peculiar to these beds; while there are left *Discina reflexa* and *Monotis substriatus*, which are undoubtedly Liassic species, and are certainly continued into these beds. We have thus analysed the evidence brought by Dr. Wright, and submit that it affords no good reason to separate these beds from the Oolite to which they lithologically belong; but rather when we consider the many new forms which are first introduced, more in number even than those that have passed up, and the *prevalence* of a new form of Ammonite, which had only appeared as an allied species before, we have, it appears to us, good grounds for believing that a change of life-forms took place—*not* in the middle of the deposition of sandstone rock, but when it first began after the deposition of the shale. We therefore, in this place, draw the line between the Lias and Oolite at the base of No. 5, [the grey sandy shale with *Lingula Beanii*] below its lowest set of nodules, as was done by the older authors, and more recently by Oppel (1856), and Simpson (1868); and for us Liassic strata are shaly to the top."*

These disputed beds have only been recognised with certainty on the coast south of Robin Hood's Bay, where they are exposed in the lower part of the cliff, and on the shore at Blea Wyke. They are not developed to any extent anywhere to the north or west of this point; and these beds being absent the junction of the Lias and Oolite is consequently sharper.

At Glaisdale, however, the ferruginous sandstone, which forms the base of the Oolites, is stated by Messrs. Tate and Blake† to

* The Yorkshire Lias, p. 20.
† *Loc. cit.*, p. 24.

contain *Rhynchonella cynocephala* and *Terebratula trilineata* associated in great numbers with such undoubted Oolite species as *Ostrea flabelloides, Ceromya concentrica, Pholadomya Heraulti, Rhynchonella subtetrahedra, Modiola cuneata,* and *Alaria composita.** This feeble representative of the Blea Wyke Beds is the only inland locality at which they have been observed, and is important from its showing the Oolitic character of the first-named brachiopoda.

The Blea Wyke Beds, as will be seen from the table, fall naturally into the two horizons of Grey and Yellow Sands, or as we prefer to call them, *The Grey Beds* and *The Yellow Beds.*

The Grey Beds.—These are really almost a grey sandy shale, and immediately succeed the shales with *Am. striatulus,* which we consider to form here the top of the Lias; but the passage from one into the other is so gradual that no line can be drawn between them. They form the fine scar known as Blea Wyke Point; and although very similar in lithological character, may be separated into two divisions the Lingula bed and the Serpula bed.

The Lingula bed is so named from the presence in it of *Lingula Beanii,* which occurs very plentifully in a line of ferruginous nodules towards the base, and scattered here and there throughout the whole of this division.

The upper three feet of these shales are very full of Belemnites, Aviculæ, and other fossils, while fragments of Crustacea and Ammonites are not uncommon. The following fossils are recorded from this bed:—

ECHINODERMATA.

Heterocidaris (Pseudodiadema) wickensis, *Wr.*

CRUSTACEA.

Eryma (Glyphæa) Birdii, *Bean, MS.*	Glyphæa sp. allied to G. rostrata.

BRACHIOPODA.

Discina (Orbicula) reflexa, *Sow.*	Rhynchonella cynocephala, *Rich.*
Lingula Beanii, *Phil.*	Terebratula trilineata, *Y. & B.*

LAMELLIBRANCHIATA.

Avicula (Monotis) substriata, *Münst.*	Gresslya donaciformis, *Phil.*
Gervillia Hartmanni, *Goldf.*	—— peregrina, *Phil.*
Pecten silenus, *d'Orb.*	—— Seebachii, *Brauns.*
—— wickensis, *Wr. MS.*	Modiola (Mytilus) scalprum ?, *Sow.*
Pinna cuneata, *Phil.*	Pholadomya fidicula, *Sow.*
Cucullæa cancellata, *Phil.*	Trigonia Leckenbyi, *Lyc.*
Goniomya angulifera ? *Sow.*	Venus tenuis, *K. & D.*

GASTEROPODA.

Cerithium quinquepunctatum, *Desl.*	Cerithium quadrilineatum, *Röm.*

CEPHALOPODA.

Ammonites aalensis, *Ziet.*	Belemnites inornatus, *Phil.*
—— comensis, *Von Buch.*	—— irregularis, *Schlot.*
Belemnites Bucklandi, *Phil.*	—— Milleri, *Phil.*

* This bed was referred by Dr. Wright to the *Opalinus* zone, which that author included in the Upper Lias. Monogr. of the Lias Ammonites, 1879, p. 149.

The Serpula Bed, which rises above the fossiliferous band at the top of the preceding, forms the base of the cliff at the corner; and, running out over the upper part of the scar produces a rough irregular surface crowded with the remains of *Serpula, Vermicularia, Avicula,* as well as *Belemnites, Rhynchonella, Terebratula,* &c.

The fossils from this bed are :—

Serpula deplexa, *Phil.*	Pinna ampla ?, *Sow.*
Vermicularia compressa, *Y. & B.*	Cardium striatulum, *Sow.*
Lingula Beanii, *Phil.*	Gresslya peregrina, *Phil.*
Waldheimia carinata, var. Blakei, *Walker.*	Dentalium elongatum, *Münst.*
Pecten intercostatus, *Wr. MS.*	Ammonites aalensis, *Ziet.* (var. Moorei, *Lyc.*)

The Yellow Beds.—These form the lower part of the strata which rise in a vertical cliff above the scar. They consist of soft yellow sandstone unevenly bedded, which throughout the main mass of the rock contains only *Belemnites* and a few other fossils; but at the top a band of rock sets in crowded with *Terebratula trilineata,* and containing the other species mentioned below. This which is known as "the Terebratula-bed" is really part of the less fossiliferous sandstone below. It is separated from the beds above by a band of soft rotten sandstone, which does not contain many fossils, but forms a marked line in the cliff dividing the Blea Wyke or Passage Beds from the Dogger.

The following list of fossils occurs in these beds, those marked T being from the Terebratula-bed in the upper part:—

CRUSTACEA.

Eryma (Glyphæa) Birdii, *Bean, MS.*	Glyphæa, n. sp.

BRACHIOPODA.

T Rhynchonella cynocephala, *Rich.*	T Terebratula submaxillata, *Morris.*
T Terebratula trilineata *Y. & B.*	

LAMELLIBRANCHIATA.

Avicula (Monotis) inæquivalvis, *Sow.*	T Gresslya peregrina, *Phil.*
Pecten paradoxus, *Goldf.*	—— pinguis, *Ag.*
Goniomya angulifera, *Sow.*	T Trigonia Ramsayi, *Wr.*

GASTEROPODA.*

Alaria arenosa, *Hud.*	Trochus dimidiatus, *Sow.*
Cerithium Beanii, *L. & M.*	Turritella quadrivitata, *Phil.*

CEPHALOPODA.

Ammonites comensis, *Von Buch.*	T Belemnites inornatus, *Phil.*
—— insignis, *Schüb.*	T —— irregularis, *Schlot.*

All the beds between the Dogger and the Lias appear to thin out rather rapidly in the steep cliffs towards the north; so that when they become accessible again, below Peak Hall, there are not more than about 15 feet of Grey Beds and 20 feet of Yellow Beds. While a little further west, beyond the great Peak fault, these beds have entirely disappeared; but to this we shall again allude in treating of the Dogger.

* Mr. Hudleston quotes these from the "Dogger Sands," but he does not state in what division they occur.

The Dogger.

Origin of the Name.—The name of this formation seems to have been derived from the Alum Works, where the nodular or lumpy character of the rock is very conspicuous; "dogger" being a local term for any hard rounded stone, whether concretionary or otherwise. Daniel Colwal, writing in the 17th century, says, "In the Mine are found several veins of stone called Doggers also Snake Stones;"* so that the name seems to have been in common use even at that time. It is therefore probable that the name arose from the tendency of the rock to weather into doggers or roundish masses inclosed in a ferruginous casing. This bed is also frequently called the "Top Seam" by the miners, from the fact of its being worked for ironstone as well as the beds in the Middle Lias.†

Synonyms and Foreign Equivalents.:—"Inferior Oolite," Conybeare, De la Beche, and others; "The Dogger," Young and Bird, Geol. of the Yorksh. Coast, p. 123, 1822; p. 129, 1828; "Eisenhaltiger Thonsandstein," Stahl, Corresp. Würtemb. landw., Vereins, p. 14, 1824; "Conchiferous (dogger) series, analogous to the inferior oolite of Bath" (upper part), Phillips, Geol. of Yorksh., p. 91, 1829; "Eisensandstein," Mandelsloh, Geogn, Prof. der schwäb. Alp, tab. 3, 1834; "Inferior Oolite" (upper part), Williamson, Trans. Geol. Soc., ser. 2, vol. v., p. 227, 1837; "Brauner Jura β. Braune Sandsteine mit Eisenerz," Quenstedt, Flözgeb., p. 538, 1843; "Calcaire lædonien" (part), Marcou, Jura salinois, p. 70, 1846; "Calcaire à entroques" (part), Cotteau, Soc. Geol. de Fr., p. 638, 1851; "Pectenitenbank, und Gelbe Sandsteine mit Eisenerz-flözen," Quenstedt, Deutsche Geol. Gesell., tab. 16, 1853; "Die Schichten des *Ammonites Murchisonæ*," Oppel, Juraformation, p. 326, 1856; "The Zone of *Ammonites Murchisonæ*," Wright, Monogr. of the Ool. Echinodermata, 1856, and Quart. Journ. Geol. Soc., vol. xvi., p. 5, 1860; "The Dogger," Hudleston, Proc. Geol. Assoc., vol. iii., p. 299, 1874; "Higher beds of the Inferior Oolite," Tate and Blake, The Yorkshire Lias, p. 19, 1876; "Zone of *Harpoceras Murchisonæ*," Wright, Monogr. of the Lias Ammonites, p. 150, 1879.

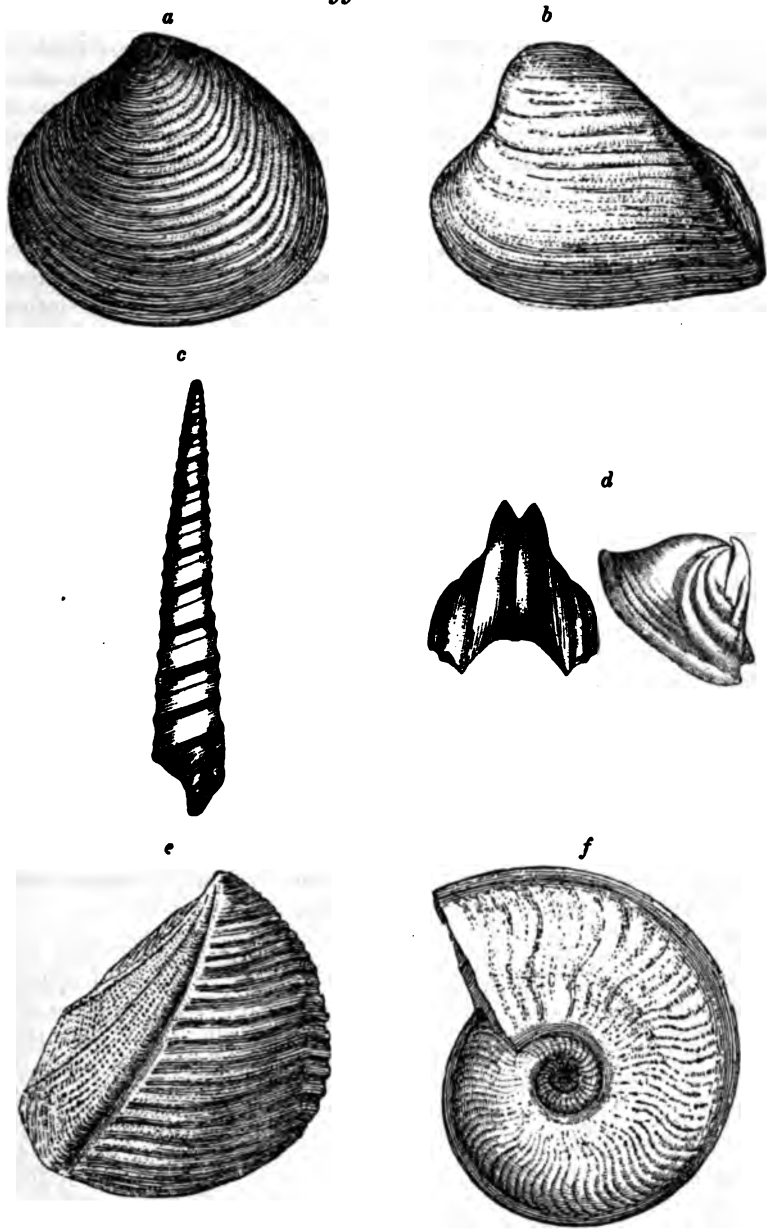
The lithological character of the Dogger is so variable that it is not easy to write a general description of the bed that shall be true for all localities. It changes from a sandstone to a limestone or a valuable ironstone, and from a fine-grained shaly bed to a nodular calcareous oolitic rock with little bedding. In some places it seems to form a passage bed between the Lias and the Lower Oolite, in others it rests on a distinctly eroded surface of the shales, while here and there it is itself cut out entirely by the Estuarine Sandstones, which rest immediately on the Alum Shale. We shall therefore obtain a better idea of its general constitution and the great variations that take place by following its outcrop from the coast inland and studying the several distinctive sections as they are exposed to view. At Blea Wyke, as we have observed, there appears to be a gradual passage from the shales of the Lias into the sandstones of the Oolite, and a much more perfect section is exposed than anywhere else in Yorkshire. Above the grey and

* Phil. Trans. vol. xii,, No. 142, p. 1052, and Lowthorpe's Abridgement, vol. ii., p. 541.

† For origin of the term "Top Seam" see note on page 448. The term "Dogger" is applied by some continental geologists to the whole of the Middle Jura (Lower Oolite). See Oppel, Juraformation, pp. 817 and 820. 1856.

FIG. 8.

Dogger Fossils.



a, Astarte elegans, *Sow.* (after Lycett and Morris) 2; *b*, Cypricardia cordiformis, *Desh.* (original) ⅔; *c*, Nerinæa cingenda, *Phil.* (after Hudleston); *d*, Rhynchonella cynocephala, *Rich.* (after Davidson) ⅓; *e*, Trigonia denticulata, *Ag.* (after Lycett) ⅔; *f*, Ammonites Murchisonæ, *Sow.* (after d'Orbigny) ½.

yellow sandstones constituting these passage beds there are from 30 to 40 feet of massive irony sandstone, separated into two portions by a ferruginous band, which is very fossiliferous, known as the *Nerinæa bed*.

The lower of these sandstones, which is about 25 feet thick, is yellowish towards the bottom, but becomes browner and more ferruginous above. It contains a considerable per-centage of iron* which gives the unweathered rock in some parts a bluish-green colour. About five feet from the base of the rock there is a marked line of small nodules, and about three feet above this a second line of nodules, which however is not quite so conspicuous as the lower one. These nodules have usually been called "pebbles," but it has not as yet been satisfactorily determined what these small lumps really are. They are of various forms, usually being about an inch or so in longest diameter, although they are frequently no larger than fine gravel. They sometimes have the appearance of being rolled fossils such as *Terebratulæ* and other bivalves, while fragments of *Ammonites*, *Belemnites*, and what may be sponges and fucoids are not uncommon, but the majority of the lumps show no organic resemblance. It is very probable that many of these little nodules or concretions are waterworn nodules from the Lias, similar to those which occur in the lower part of the *Striatulus*-shales; in which case "pebbles" is a correct designation of them, although exception has been taken to the term.

Thus Mr. Hudleston speaking of these nodules says, "Besides these amorphous lumps there are corals, bits of shells, and bodies full of holes that may have been sponges. One of these porous nodules on analysis was found to consist principally of calcic phosphate, ferrous carbonate, a little calcic carbonate, and a little brown oxide of iron. The insoluble residue consisted of a silvery sand with a little mud. A smooth round nodule, with large oolitic grains inside, was found to be similarly composed, except that the insoluble residue consisted of a fine black mud, which burnt with an empyreumatic odour to a whitish clay.

"It would be too hasty a conclusion perhaps to infer from the analysis of two nodules that they are all phosphatic; yet I apprehend that a more extended examination would only confirm such an inference. The chief difference between these and the ordinary phosphatic nodules of the beds below the Chalk consists in the calcic carbonate having been partially replaced by ferrous carbonate. It is evident, however, as previously observed, that those writers who took these things for pebbles were mistaken. That a stray pebble may occur here and there, like the lydian stones &c. of the Cretaceous phosphate beds, is very probable, but as regards the Nodule bed of the Dogger at Blea Wyke they must be very rare."†

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* Mr. Hudleston says 38 per cent. Proc. Geol. Assoc., vol. iii. p. 301.
† Proc. Geol. Assoc., vol. iii. p. 301.

At many inland localities, especially to the west and in the Howardian Hills, the pebbles appear to be chiefly composed of bits of ironstone, sandstone, limestone, quartz, and other hard rocks; the phosphatic nodules, which are so plentiful at Peak, either do not occur or are much less numerous.

The Nerinæa bed which caps the sandstone varies in thickness from 1 ft. 0 in. to 1 ft. 6 in.; it is almost composed of fossils and contains *Nerinæa cingenda*, *Astarte elegans*, *Trigonia*, and Coral in great abundance; it is from this band that nearly all the Dogger species have been derived. The fossils contained in the list on page 177 are mostly from this band.

The upper bed of sandstone is about 10 feet thick on the south side of Blea Wyke Point, where it forms a bold reef of rocks that stands out conspicuously from the fallen blocks of sandstone which cover the shore at this spot.

This block consists of very ferruginous sandstone which breaks up into irregular masses separated by seams filled with brown oxide of iron, in a manner which is very characteristic of the Dogger in general.* It contains fragments of quartz scattered throughout: the irony matter in the rock is frequently aggregated together in nests, which are harder than the sandstone, and stand out in small projections that give it a rough, irregular appearance.

It is this upper portion of the Dogger which is continued to the north, and which is exposed in the several sections to be treated subsequently: the beds below all die out and are not known for certain anywhere excepting in this interesting exposure at Blea Wyke.

From the spot where it rises above high-water mark the Dogger may be followed along the top of the lower cliff to the great exposure close to the fault below Peak Hall. Here the reddish-brown ferruginous rock, which is much fractured and traversed with diagonal seams of oxide of iron, thickens out very rapidly; in fact the rock appears to lie in a hollow of the other beds, or they pass laterally into this class of rock. It is not very easy to determine exactly what takes place at this point. A short distance to the south there is a considerable thickness of yellow sandstone below the bands of small nodules; which, by carrying the eye along the cliff, appears to strike directly into the lower part of this rock: the junction between the two is, however, hidden by fallen blocks of sandstone, so that it is not possible to say whether these yellow sandstones become more ferruginous, and pass into the true Dogger, or whether the latter lies in a denuded hollow.

When these beds appear again on the opposite side of the great Peak fault they are much reduced in thickness. At the Alum Works, which are only half a mile from the exposure in the cliff, the section is :—

* Mr. Hudleston says some of these contain from 28 to 34 per cent. of metallic iron. *Loc. cit.*, p. 299.

Section at Peak Alum Quarry (east end).

		Ft. In.	Ft. In.
	Massive sandstone with a good deal of carbonaceous matter in lower part.		
The Dogger.	Soft irregular ferruginous sandstone - -	1 0 to	1 4
	Irregular band of concretious or small nodules -	0 1 to	0 4
	Ferruginous calcareous sandstone, vertically jointed, with white specks and a very few small nodules - - - - - -	1 8 to	1 10
	Band full of nodules or concretions, containing *Terebratula* and other bivalves - -		0 6
	Calcareous concretionary sandstone with some shale, becoming more like separate nodules at south end of quarry* - - -		1 6
	Blue shale.		
	Average thickness, about		5 0

There thus appears to be a diminution of about 100 feet in the thickness of the beds between the top of the Dogger and the top of the Alum Shale; the whole of the Striatulus Shales and Blea Wyke Beds have vanished, and the Dogger itself is reduced from 28 feet to about 5 feet in the short distance between Blea Wyke and the nearest Alum quarry, about a mile in a direct line.

Mr. Hudleston suggests that the preservation of the beds at Blea Wyke, while they have been entirely removed in so short a distance, may be due to the Peak fault being partially pre-oolitic in date; so that these beds were let down and protected before the deposition of the Oolite.†

The Dogger, however, in Rosedale and Bilsdale lies in troughs, the sides of which cut out the strata below quite as sharply as this: and, as it appears to descend into lower beds below Peak Hall, it is probable that something of the same sort takes place here, but we will return to this subject further on when treating of the physical conditions under which these beds were deposited.

‡ For some distance to the north this rock maintains much the same appearance; weathering into rounded lumps or *doggers*, enclosed in a ferruginous crust. Its outcrop is easily traced westwards, as far as Howdale Beck, after which it becomes obscured by Boulder Clay. No fossils were observed in any of the exposures along this part of the outcrop. In the small stream near Pretty House the typical ferruginous sandstone crops out, and is about 12 feet thick, but apparently unfossiliferous: from this point it is not seen again till Ramsdale Beck is reached, where from the smallness of the exposure its thickness cannot be exactly ascertained. Its junction with the Lias is cut through at Row, and in the road above Park Hill; in both of which sections the Dogger is about 18 inches thick. It reaches the cliff at Hawsker Bottoms, and can be examined and measured on the pathway

* Mr. Hudleston includes this bed in the Lias. *Loc. cit.*, p. 303.

† *Ibid.*, p. 304.

‡ These details are largely from the information given by Messrs. Reid and Barrow, in the Memoirs of the Geological Survey, Explanations of Quarter-Sheets 95 N.W., 96 N.E., 96 N.W., 96 S.W., and 104 S.W., S.E.

down the cliff, known as Sawdon's or Jackass Road, where the following section may be seen :—

	Ft.	In.
Alternating sandstones and shales, three small coal seams near the base - - - - - -	80	0
Typical dogger sandstone with pebbles, casts of *Belemnite* guards and other shell fragments - - -	5	0
Band of small nodules or pebbles - - - -	0	2
Massive ferruginous concretionary nodules - - -	1	0

The Dogger continues in the cliff, and opposite Nype Howe is only a few feet above high-water mark, the section here being :—

		Ft.	In.
	Sandstone - - - - - - -	20	0
	Dark shales and thin sandstone - - - -	20	0
	Coal - - - - - - -	0	4
	Sandstone (carbonaceous root-marks) - -	3	0
Dogger 6 ft. 8 in.	Ferruginous sandstone - - - -	3	0
	,, ,, with pebbles - -	3	0
	Nodular band - - - - - -	0	8
	Alum shale.		

The coal seam is continuous for only a short distance further north, but can be followed for a considerable way to the south. The Dogger itself has the upper part full of casts of vertical *Equisetites*, but contains very few other fossils.

The section remains the same as far as the lighthouses, where a thick mass of false-bedded sandstone descends and cuts out the Dogger for a few yards.

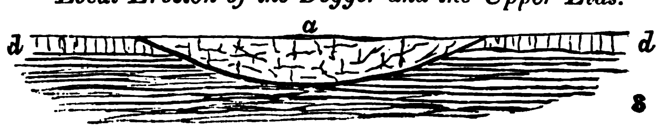
In Saltwick Bay this bed is 2 feet 6 ins. in thickness, very hard, and with less silica than usual: at the base there are many of the so-called pebbles, some of which are waterworn fragments of *Belemnites* and *Ammonites*, the latter being unmistakably Lower Lias forms.

Approaching Whitby, the Dogger becomes still more ferruginous, nodules of ironstone appearing above the main part of the bed; still it is far too siliceous to be of any commercial value as an ironstone.

Just before reaching Whitby, the phenomenon seen under the lighthouse is repeated. After the Lias and the Dogger were deposited, a small local current has eroded a hollow through the latter and a few feet down into the former. Sand has afterwards filled up the hole thus formed.

FIG. 9.

Local Erosion of the Dogger and the Upper Lias.



a. Estuarine Sandstone *dd.* Dogger *s.* Alum Shale.

From this point the Dogger rises in the cliff till it is about 40 feet up near the East Pier; turning south, it descends rapidly to the river bed inside the harbour.

A large fault that runs through the harbour throws the Dogger down below sea-level, and it is not seen again till it crops out a little way up Raithwaite Gill. Here the bed was formerly worked on a small scale by an adit; but the Boulder Clay has now slid over it, and entirely obscured the ground. Proceeding westward the south bank of the high road shows the following section:—

	Ft.	In.
Sandy calcareous ironstone with ferruginous joints	2	6
Calcareous and ferruginous sandstone, many pebbles	1	6
Concretionary, ferruginous sandstone, pebble bed	2	0
Ferruginous, pebbly sandstone, pebble bed	0	10
Ferruginous calcareous sandstone	3	2
Very hard nodular ironstone	1	2
	11	2

Red ferruginous shale passing to Alum Shale.

The part of the bed worked appears to have been the last nodular ironstone band, which was thicker in some places; but its unreliability, both as regards quality and thickness, caused it to be abandoned some years ago.

For a short distance the Dogger continues in the face of the cliff, it then plunges under the Boulder Clay, and is completely obscured for about a mile and a half, till it reappears in the bed of the little stream east of Trucky Rock Hole. Another and better exposure is seen in the stream that has cut out the latter place. Here the Dogger consists of two beds, each very hard and solid, weathering into rounded blocks with ferruginous casings. The upper bed is a red ferruginous sandstone, the lower of a much lighter colour, and more calcareous. In it may be found many fossils, though, as a rule, only a few species, such as *Terebratula trilineata*, *Pholadomya Sæmanni*, *Trigonia*, &c.

A very clear section is seen again in Rock Hole, just north of Rock Head, and in Biggersdale Hole, where a fair number of fossils may be collected.

The top only is seen in the bed of the two streams that flow through Mulgrave Woods, and the ground north of the old castle is much obscured by Drift. The Dogger caps the Alum Shale at Hell Scar, due south of Mulgrave Castle, and from this place the outcrop is sufficiently clear as far as the Lythe Road, where a small tongue of clay obscures its course just before appearing in the Lythe Alum Works.

Here is, perhaps, the most accessible of all the sections of this bed. The following details were measured at the south end of the great quarry:—

	Ft.	In.
Ferruginous jointed concretionary sandstone	2	6
Ferruginous shale	0	10
Dogger band	1	0
Ferruginous shaly sandstone, pebbles	1	8
Ferruginous sandstone, weathering into large blocks	4	6
	10	6

The lower part of the last bed contains many pebbles and fossils, the latter chiefly in nests. *Terebratula trilineata* occurs in vast numbers, *Lingula*, *Vermicularia*, &c., being less common, but all occurring as casts, and not easily determinable.

For some distance to the north, the Dogger becomes thicker, and less ferruginous; in fact, a sandstone, having a slightly oolitic appearance. There are ferruginous nodules at the top and base, and "pebbles" throughout.

Just north of Overdale, the cliff presents the following section:—

	Ft.	In.
Massive false-bedded sandstone - - - -	40	0
Carbonaceous shale, with soft jet - - - -	50	0
Sandstone - - - - - - -	5	0
Carbonaceous shales - - - - - -	1	6
Ferruginous shale - - - - - -	1	0
Slightly ferruginous sandstone, pebbles - - -	8	0
Shale, with two rows of ironstone nodules - - -	4	0

Further north, though visible in the cliff, this bed is quite inaccessible till reaching Kettleness Alum Works. The section here differs little from that last given, except that there is more ferruginous matter. This character becomes so much more marked a little to the west, that a trial-hole was driven into the Dogger just against the small stream (Cat Beck) that passes by Kettleness village, and the following section was proved:—

	Ft.	In.
Typical "dogger," very ferruginous sandstone, pebble bed -	4	0
Shale, ferruginous - - - - - -	1	6
Ironstone, of good quality - - - - -	0	5
*Ferruginous sandstone with pebble beds - - -	4	0
Ironstone, with jet fragments - - - -	1	2
*Ferruginous sandstone - - - - -	2	6
Shale - - - - - - - -	0	11
Ironstone full of pebbles - - - - -	0	5
Ironstone, hard, and of good quality - - -	0	8
Total - -	15	7

After keeping in the face of the cliff, the outcrop turns inland along the east side of the small stream below Claymoor, the character of the rock being much the same. It then turns north, seaward again, and a trial-hole has been driven into it close by the old limekiln, about the centre of the bay. Though highly ferruginous, it is far too siliceous to be considered an ironstone. The old valley, through which the present Staithes Beck used to flow, is completely filled by Glacial deposits, and nothing is seen of the Dogger along its flanks on either side.

North-west of Runswick Bay is an outlier of Lower Oolites, with the Dogger at the base. Over the whole of this area the bed is more than usually ferruginous, and has been extensively mined; its outcrop, however, can be seen only in the face of the cliff. The following section was measured just north of Runswick:—

* This might sometimes be called a siliceous ironstone; it is very variable in character.

	Ft.	In.
Ironstone, hard and compact	0	4
Sandstone, ferruginous	1	0
Ironstone, very hard	0	7
Ferruginous, oolitic, concretionary sandstone	1	6
Ironstone	0	2
Sandstone, ferruginous	1	0
Sandstone, with ironstone nodules	4	0
Total	8	7

Alum shale.

From this point it rapidly becomes more ferruginous and less siliceous, in fact, an ironstone; the following section is seen at an old adit in the cliff face at Rosedale Wyke (now better known as Port Mulgrave):—*

	Ft.	In.
Hard stone (good quality)	1	0
Ferruginous marl	2	3
Hard stone	0	3
Pebble-bed	0	2
Grey stone	0	3
	3	11

In working, this bed was found to vary between two and four feet in thickness. Towards the south side of the Oolitic outlier, near Hinderwell, the bed is cut out entirely by what the miners term a "freestone baulk," which is simply the repetition, on a larger scale, of the phenomenon described as seen near Whitby.

The exact position of the Dogger now becomes very uncertain over a large portion of its outcrop; for south of Hinderwell the Boulder Clay hides every trace of it, and there is no section within some 50 feet of it in Borrowby Dale. The Drift, however, becomes thinner along the face of Rousby Hill, and the outcrop is seen again in a little gully that opens into Rousby Beck, just under the Keeper's Lodge.† Here the section is:—

	Ft.	In.
Impure ironstone	5	0
Shale	2	0
Ironstone dogger (fossils)	0	6
Shale	1	0
Dogger band	0	6
	9	0

Alum shale of a light colour below.

About 100 yards further south the following section was measured, giving a fair idea of the rapidity with which the Dogger changes:—

	Ft.	In.
Sandstone	20	0
Sandy ironstone, with nests of shells	3	0
Shale	3	6
Dogger band	0	3
Shale	1	0
Dogger band	0	3

Alum shale.

* Proc. Cleveland Institute of Engineers. 31st May 1880.
† Low House on One-inch map.

The outcrop can be followed from here into the bed of the stream, after which it passes under the Boulder Clay of Rigg Lane, and reappears on the west side of Easington Beck, but only part of the bed is exposed. The cutting of the Redcar and Whitby railway running alongside the west bank of Easington Beck shows the nature and thickness of this bed. It is an impure ironstone, about three feet thick, more siliceous than further north, with but few fossils, which for the most part are comminuted and unrecognisable.

Further north the outcrop is covered by Drift till the cliff is reached at the Boulby Alum Works; where several instances occur of the denudation of part of the Dogger, the eroded hollow being filled with Estuarine Sandstone. In its normal condition the section is:—

	Ft.	In.
Hard oolitic ironstone	1	1
Softer stone, shelly	2	0
Ferruginous shale	0	6
Sandy ironstone dogger	0	4

The first band is a good ironstone, while the second varies much, sometimes being of fair quality, at others very impure. The whole is essentially an ironstone here, but its quality deteriorates somewhat going further west.

The section in Lofthouse Alum Works is:—

		Ft.	In.	Ft.	In.
Massive sandstone				40	0
Carbonaceous shale				10	0
False-bedded sandstone				15	0
Ferruginous shale				12	0
Dogger	Pebble band on ironstone	0	6	4	6
	Hard shale and ironstone bands	3	6		
	Impure ironstone bands*	0	6		
Alum shale.					

From the bed marked (*) Messrs. Tate and Blake record the following fossils†:—*Actæon Sedgvici*, *Actæonina mitræformis*, *Dentalium entaloides*, *Ostrea flabelloides*, *Lima toarcensis*, *Pecten lens*, *Mytilus imbricatus*, *M. cuneatus*, *Perna isognomoides*, *Leda rostralis*, *Cucullæa cancellata*, *Quenstedtia oblita*, *Alethopteris polypodioides ?*, fragments of pinnules with sori. Also species of *Belemnites*, *Anomia*, *Plicatula*, *Corbula*, Entomostraca, *Serpula*, *Pentacrinus*, &c.

After leaving the Alum Works, the base line of the Oolites recedes inland from the cliff, and owing to the thick downwash is not actually seen for a considerable distance, though its position is clear enough. In Deepdale the Dogger passes round an old Drift-filled valley, and its exact position is very uncertain. The presence of this valley was proved by the new engine-road down into Whitecliff Mine, which was cut for a considerable distance in Glacial deposits.

† The Yorkshire Lias, p. 26.

The Dogger crops out again in Whitecliff Beck, the small stream that flows from Lofthouse to join Skinningrove Beck, the section being—

	Ft.	In.
Very dense ironstone, slightly oolitic, containing *Terebratula punctata*, *Rhynchonella cynocephala* (?), &c.	0	10
Ironstone, softer and more oolitic	0	6
Ferruginous sandy bed, almost a sandstone	1	2
Hard ironstone, small fossils in lines or layers	0	9
Marly ironstone, a mass of fossils	1	6
Shaly calcareous ironstone, with the characteristic pebbles	0	6

From the last two beds fragments of *Ammonites* and *Belemnites* are occasionally found, but other fossils are extremely abundant, such as *Thecosmilia gregaria*, *Terebratula trilineata*, *T. punctata*, *Rhynchonella cynocephala*, *R. tetrahedra*, *Ceromya bajociana*, *Pecten*, *Avicula*, &c.

There is a level from Liverton shaft through this bed to the day, and the ironstone brought out has yielded a great number of fossils.

To the south and west the outcrop is obscured by Drift, and though its position can be fixed with tolerable accuracy, it is not seen again till Warsett Hill, overlooking Huntcliff, is reached. The Dogger here makes a small crescent-shaped spread; the Ironstone and ferruginous marl being quite bare even of vegetation in one or two places. It is evidently much the same as at the outcrop last described, but perhaps a trifle thicker. Just south-west of Warsett Farm, a well was sunk 48 feet to the Dogger, fragments of which can still be seen.

Going south along the side of the hill the outcrop is clear enough as far as Brotton Pit; afterwards it again crosses a line of old valley, and is lost sight of, but reappears in the alum quarry called Hagg Hole.

Here the section is as follows:—

	Ft.	In.
Carbonaceous shale	5	0
Shale, with thin streaks of ironstone	5	0
Ironstone nodules	0	2
Shale	2	0
Ironstone	0	1
Shale	0	4
Ironstone	0	3
Shale	0	7
Ironstone	0	3
Earthy ironstone, nodules, with *Belemnites*	0	6

Alum Shale.

This section is typical of the representative of the Dogger or Top Bed over a considerable district to the south and west; both in Eston and Upleatham Hills for example, and also in the face of the Guisbrough escarpment. Indeed, it is doubtful whether there is any Dogger really present in some cases; but its absence is simply due either to non-deposition, or to the ferruginous nodules containing no distinctive fossils, and is not owing to its

having been denuded away before the deposition of the Estuarine Series as is seen on the coast near Whitby.

In North Skelton and Skelton Park Pits, the Top Bed is given as "Ironstone nodules in shale"; and the sections in the old alum quarries about Guisbrough show 10 feet of ferruginous shale with ironstone nodules immediately above the Alum Shale. A similar feature is seen both in the Upleatham and Eston Hills, the pits in the latter passing through from 5 to 12 feet of "shale with ironstone nodules."

It is not till we reach the district south of the prominent headland of Great Ayton and Easby Moors that the Dogger again becomes a distinctly recognizable bed.

In the neighbourhood of Kildale it consists of a 10-inch band of hard ironstone, containing *Pholadomya Heraulti?* in great numbers, resting upon 5 feet of marly, shelly stone that decomposes on exposure to the air. About 2 feet down this latter bed contains lines of nodules, which are somewhat phosphatic and apparently water-worn; these toward the base of the stone are extremely abundant.

Passing round to the south, in the Ingleby escarpment, shales with rows of nodules and fragmentary fossils are the only representative of this bed; and, there being so many clear exposures of the junction of the Lias and Oolite, the absence of any characteristic bed is very marked. On the west side of Hasty Bank the Dogger, which comes in as a wedge, assumes the character of a ferruginous shelly limestone, and continues as such for a great distance to the west and south-west.

Section of the Dogger at Wain Stones, Hasty Bank.

	Ft.	In.
Ferruginous dark shale	15	0
Shale with ferruginous Doggers	3	0
Very ferruginous limestone	0	6
Soft, dark shale	3	9
Limestone, flaggy, oolitic, ferruginous, full of comminuted shells	3	0
Soft, dark shale	0	4
Ferruginous, calcareous, nodular bed	2	0
Shale, with water-worn *Belemnites*, &c. (Pebble bed)	2	0

On the west side of Bilsdale, about a mile due south of Wain Stones,* the Dogger presents a very unusual and interesting appearance. It is a strong echinital limestone with many fossils, principally *Terebratula trilineata, Modiola imbricata, Trigonia* sp. and *Trochotoma calix*, having a thickness in one place of about 20 feet; it lies in a distinctly eroded hollow in the Upper Lias, this hollow being more than a mile in length; and in one place, the limestone descends to within 30 feet of the Jet Rock. But we will return to this again presently.

* This name is said to have been derived from the fancied resemblance of this group of rocks to a waggon with team and driver. Formerly there was here a horizontal block of sandstone reposing on two upright ones. Young's Hist. of Whitby, vol. ii., p. 768.

Throughout the rest of Bilsdale the only representative of this bed is the shale with one or more rows of ferruginous nodules; and in some cases the Estuarine Sandstone rests immediately upon the Alum Shale.*

Before proceeding further with the main outcrop to the west and south, it will be as well to consider the development of the Dogger in the several inliers that occur over the moors to the east, fringing the deep valleys which are cut through to the Lias: these latter are nearer and more intimately connected with the district we have been describing than with that to the west of Bilsdale.

The largest and most easterly of these inliers is that along the valley of the Esk, which but for the accident of the fault at Whitby would have been part of the main outcrop. In this valley between Ruswarp and Sleights, the Dogger is first seen in a small stream near the railway, and again in an old quarry a few yards off, where it is about eight feet thick; after which it is hidden by Boulder Clay until Ugglebarnby in Iburndale is reached. In quarrying stone to build the church the upper part of the Dogger was exposed. A trial-hole was driven into the bed, but it proved valueless as an iron-ore.

At Little Beck Alum Works, and along the east side of the dale as far as Falling Force, very fine exposures occur; here the sandstone is remarkably full of soft white specks, and contains sufficient carbonate of lime to effervesce with acid.

The number of fossils in it, especially in the lower part, is considerable; but as they are generally casts their specific identity is uncertain. *Lingula Beanii* is very abundant, as is also *Terebratula trilineata.* Two species of *Pecten*, two of *Trigonia*, a *Nerinæa*, occasional casts of an *Ammonite*, and fragments of *Belemnites* are among the more common fossils. The thickness of the Dogger at the Alum Works is about 15 feet.

On the west side of Iburndale an interesting section is seen in Wash Beck, the central portion of the bed being a coarse siliceous grit. The other exposures are at the Thornhill Alum Works, and the road-side above Sleights in Iburndale, and at the Alum Works in Eskdale. In the latter dale the Dogger is about 12 feet thick, and has often been tried as an iron-ore, but always without success.

Immediately above the ironworks at Grosmont trial-holes have been made in the Dogger, but owing to its sudden variations in character it was found to be of no value as iron-ore. In one of these drifts, by the road-side on the east, the bed is 4 feet thick and contains 24 per cent. of iron. The outcrop is remarkably clear about here; a drift in the banks of Lythe Beck shows 12 feet of highly fissile and ferruginous sandstone with many carbonaceous fragments, but apparently no marine fossils. South of this it passes through Crag Cliff Wood to the Whin Dyke, where it is seen calcined for a few feet In the little stream close by it consists of soft brown sandstone at the base, with 10 feet of more calcareous beds above, the usual band of rolled nodules being absent. It continues south through Blue Ber Wood as a

* Continued on p. 171.

calcareous sandstone; and, then gradually becoming more ferruginous, passes into a concretionary ironstone, this character being well seen in a road above the smithy at Beck Hole, where the nodules with a few badly preserved fossils occur at the base. At Hollins Wood the Dogger descends into the bed of the river, making an exceptionally fine outcrop; it is here about 15 feet thick, and consists of a bluish, coarse-grained, impure ironstone, the grains being so large as to be almost pisolitic. A trial-hole was made close by, and the upper part of the bed analysed, which was found to contain about 36·7 per cent. of iron, while another analysis from the same part of the seam, about 100 yards off, yielded only 19·32 per cent. of iron. A little north of this some ironworks were erected to smelt the stone obtained from this bed, but they have been long since disused.

On the west side of the Murk Esk, owing to landslips, the outcrop is more obscure, but its general course is quite clear from the numerous drifts into it. At Cat Scar, to the north of Grosmont, the Dogger, which is about 20 feet thick, is essentially a ferruginous sandstone, very flaggy, and the lower part of the bed containing 23 per cent. of iron. At Cote Banks it is similar in character but thinner.

Opposite Egton, a section in Blue Beck shows:—

	Feet.
Earthy oolitic ironstone - - - - - - -	12
Ferruginous shale - - - - - - -	2
Alum shale.	

Similar beds are again seen in the road-cutting above Scalby Hill. In Egton Grange there are no sections, the beds being entirely hidden by Boulder Clay.

In Glaisdale the Dogger, though scarcely more than a ferruginous sandstone, has been worked for iron-stone, and the trial-holes and natural scars yield abundance of sections. On the north side of the dale the Dogger rises from beneath the Alluvium close to the Iron Works. The high dip, about 9°, carries it above the houses at Under Hill, so that the trial-drift there is about 100 feet above the stream. The section shows:—

		Ft.	In.
	Estuarine shales and sandstones, with ferns.		
Dogger	Irony shale - - - - - -	1	0
	Ironstone, rubbly and weathering into spheroids - - - - - - -	2	6
	Ferruginous dogger with irony partings - -	7	0
	Nodular base - - - - - -	1	0
	Blue shale.		
	Total - -	11	6

The stone is too poor for profitable working.

Westward the Dogger rises steadily, and a series of drifts at and near Post Gate Hill show similar ferruginous beds with a total thickness of about 12 feet. The spoil heaps yield a greater abundance of fossils than in any other part of this district, but they are generally in the state of casts. Above Apple Garth

Hall the Dogger becomes more flaggy, and further west, at the Sandstone Quarry, near High Hardhill, it has lost all claim to be called an ironstone, as it consists of sandy micaceous shale or sandstone. Southward the bed thickens, till at the south-west corner of the dale it measures 16 feet, the upper portion being flaggy. Returning by the south side of the dale the Dogger again becomes ferruginous and fossiliferous, so that on the east side of Winter Gill it has been tried for ironstone. A section in an open quarry half a mile north-east of Gill Beck shows:—

		Ft.	In.
	Flaggy estuarine sandstone and shales	10	0
Dogger	Flaggy grey ironstone, with comminuted shells?	2	0
	Earthy ironstone with irony partings	3	0
	Nodular rubbly band, the nodules made up of oolitic ironstone (perhaps conglomeratic)	1	3
	Earthy ironstone as above, *Terebratula trilineata*, &c.—fossils principally near the base	9	6
	Soft blue shale.		
	Total	25	9

In Bank House Beck the section is:—

	Feet.
Sandstone and shale	4
Oolitic earthy Dogger	6
Shale.	

East of this point, though there are no clear sections, the Dogger appears to be very thin.

On the north side of the Esk there is a section in the small stream that flows down from Aislaby past Woodlands, which is as follows:—

	Ft.	In.
Typical Dogger sandstone	3	0
Soft sandy shale	5	0
Whitish sandstone, fossiliferous in lower part	2	0
Total	10	0

The fossils are mostly casts, a species of costate *Trigonia* and *Pholadomya Sæmanni* being most abundant.

At Egton the Dogger is seen in each of the gills leading to Egton Bridge, but for some distance both east and west of this point it is entirely hidden by Drift. At the western corner of Limber Hill Wood it reappears as a fine-grained ferruginous rock, full of variously coloured specks, and containing a few fossils.

Between Glaisdale End and Lealholm Bridge the dip carries the Dogger beneath the river bed. In Crankly Gill—the gorge of the Esk above the latter place—it reappears, and at the most southern part of the bend of the stream the section is:—

		Feet.
Dogger	Ironstone	4
	Nodular band	1
	Fossiliferous Dogger	10
	Alum shale.	
	Total	15

North of the Esk the Dogger has been tried for ironstone at Oakley Side, and on the south side also at Finkel House in Great Fryup, where it has a thickness of 25 feet. Between Finkel House and Glaisdale Wood Head it can easily be traced, though measurable sections are rare. A very good exposure in Yew Grain Scar at the head of Great Fryup shows:—

	Feet.
Ferruginous sandstone, shaly and fossiliferous at the base	32
Alum shale.	

At Slidney Piece another section gives:—

	Feet.
Estuarine shale	15
Ferruginous sandstone, slightly false-bedded	10
Shale	7
Dogger with fossils	20
Total	52

The scar beneath Head House, at the entrance to Great Fryup, shows 5 feet of ferruginous Dogger on an irregular surface of white false-bedded sandstone. This sandstone, which reaches a thickness of 15 feet, is probably only an exceptional modification of the more usual ferruginous Dogger.

In Little Fryup, though the Dogger can be traced easily, there are no good sections.

On the west side of Danby Dale the Dogger and Lias are so similar in lithological character near the junction that it is difficult to draw an exact line between them. A section close to Double Dike shows:—

	Feet.
Estuarine shale and a little sandstone.	
Shaly Dogger	12
Shale	5
Very shaly Dogger with an undeterminable *Ammonite* (the lower 2 or 3 feet may perhaps belong to the Lias)	12
Alum shale.	
Total	29

In the main valley of Westerdale the only evidence of the existence of the Dogger is in the road-cutting at Top End near Westerdale Village. The section shows:—

	Feet.
Sandstone (estuarine).	
Shaly Dogger	13
Alum shale.	

Beneath Esklets Crag this has changed to a flaggy micaceous sandstone with wood, small *Avicula*, and an undeterminable *Ammonite*.

Probably a similar change prevents the Dogger from being clearly identified in Basedale. At the head of Black Beck the section is:—

	Feet.
Flaggy sandstone, the lower part with oolitic ironstone, ferns, and much lignite - about	30
Shale, with *Ammonites communis*	6
Total	36

In Bransdale sections are confined to the south portion of the dale, the best being one south of Stork House, which gives:—

Estuarine shale	5
Fine-grained, dark, flaggy sandstone	25
Alum shale.	
Total	30

The only places where the Dogger can be seen in Farndale are in the immediate neighbourhood of the mines above the church, which were opened in the hope of obtaining the valuable magnetic ironstone worked in Rosedale. The Dogger appears to be about 25 feet thick, but thins out rapidly in both directions. A trial-hole on Blakey Moor showed only 5 feet of poor ironstone.

In Rosedale the Dogger has been extensively worked for ironstone, but the distribution of the stone is curiously partial. At the head of the dale the beds are so different from those a mile away that, had they not been traced continuously, it would be difficult to recognise them as belonging to the same horizon. A section in the stream near Black Intake shows:—

	Ft.	In.
Flaggy sandstone with *Avicula*, wood, and ironstone with shale	10	0
Hard shale	8	0
Line of tough ironstone shale with *Belemnites*, and small tough nodules	0	6
Alum shale.		
Total	18	6

To the south-east the ironstone improves, and has been extensively worked in Rosedale East Mines. A quarried face at Moor Hill exposes:—

		Ft.	In.
	Carbonaceous shale and rubbly sandstone	10	0
Dogger	Sandstone, soft, fine-grained, with white specks	9	0
Dogger	Hard, blue, very micaceous shale, very like Lias	4	8
Dogger	Ironstone, tough and poor, with white nodules, often left as roof in the mine	1	0
Dogger	Ironstone, fossiliferous, oolitic, rather poor	3	0
Dogger	? (hidden)	2	0
Dogger	Ironstone, very poor and soft, full of casts of *Belemnites*—the "Belemnite" of the miners	7	0
Dogger	Ferruginous sandy shale with casts of *Belemnites*	7	0
	Alum shale	10	0
	Total	53	8

The workable ironstone in the East Mines varies from 4½ to 14 feet, averaging, according to the manager, about 6½ feet. For a short distance there is a seam of magnetic stone about 14 inches thick, containing *Pecten demissus*. This was the only magnetic ironstone found in the East Mines. It formed a lenticular mass in the ordinary stone, and showed a similar oolitic structure.

On the opposite side of the dale, near Sherrifs Pit, the seam is much more regular, measuring about 6 feet.

In the West Mines the most valuable stone is a magnetic ore lying in two narrow channels or troughs cut in the Alum Shale. These masses of magnetic ironstone, forming an abnormal thickening of the ordinary Dogger, are known respectively as "Kitchen's Deposit" and "Garbutt's Deposit." They are about 70 feet thick in the centre, and extend in a south-westerly direction about a quarter of a mile into the hill. Though worked for a good many years there is still, according to Mr. Roscamp's estimate, about 200,000 tons left. No other channels, or continuations of these, have yet been discovered, but the most probable place for finding them, on the opposite side of the dale immediately north of Mill Farm, appears not to have been tried.

Returning again to the main outcrop, we noticed that on the west side of Bilsdale the Dogger, which is much altered in character, lies on an old eroded surface of the Lias.

Where first met with in this area, at the north east end of Vittoria Plantation, it is a siliceous and ferruginous limestone some 6 feet thick. Towards the south it thickens rapidly to nearly 50 feet, and becomes a ferruginous echinital limestone, a species of *Acrosalenia* being extremely abundant. On the east side of the hill this limestone is lying in an eroded hollow of the Upper Lias, and at the extreme south end of Cold Moor a similar limestone is seen coming down to within a few feet of the Jet Rock. On the west side of Vittoria Plantation near the north end a trial-hole has been made into the Dogger, which is here 20 feet thick, and quite a different rock to what it usually is, being more like the same bed on the coast, especially at the Peak, Robin Hood's Bay. It is so full of fossils as to be a marl, and rapidly disintegrates on exposure to the atmosphere. It contains vast numbers of little concretions, which contain a considerable proportion of phosphate of lime, and seem often waterworn.

The rock as a whole contains about 20 per cent. of iron. Owing to the rapid disintegration of the bed it is difficult to determine the fossils in it, but among the more abundant are the following:—*Ammonites,* 2 species, *Trochotoma calix, Eucyclus,* sp., *Lima electra?, Modiola imbricata, Ostrea gregaria, Trigonia pullus?, Terebratula trilineata, Acrosalenia,* sp., *Thecosmilia,* sp., *Vermicularia,* sp.

On the outlier of Dromonby Hill the Dogger is merely represented by a few bands of doggers or nodules, but on the little outlier of Wath Hill to the south it is again a ferruginous limestone from 3 to 6 feet thick.

In Raisdale it is also merely represented by nodules at the east end, but in the centre of the dale it is a ferruginous limestone from 3 to 8 feet thick, which character it maintains as far as the fault. To the north of this it quickly thins away, a little band only of the somewhat phosphatic nodules representing it.

Towards the north end of Carlton Moor it is too thin to be traced, but a few doggers may represent it in the alum quarry, as well as along the west side of the hill, and in the outlier of Whorl Hill where nothing is seen of this bed.

A boring put down in a quarry over the entrance to Swainby Mine showed no distinct representative of the bed, and none can be seen (though it may exist in places) till the head of Thackdale is reached, where it is 3 feet thick, being shaly in the middle and very fossiliferous at the base. It would appear to maintain much the same character and appearance round the head of Scugdale, for at Rank Crag it is 4 feet thick, while south of this, and at Blue Scar it is 5 feet.

The section at the latter place is—

	Ft.	In.
Sandstone - - - - - - -	15	0
Shale - - - - - - - -	2	0
Dogger, impure ferruginous limestone - - -	5	0

This shale, which is very similar to the Alum Shale, generally succeeds above the Dogger, where the latter is a calcareous bed. In Harfa Bank there is no good representative of this part of the Lower Oolite, and it is not till approaching Limekiln Bank that exposures of the Dogger are again seen. Here it is an impure fossiliferous limestone, or rather a hard shelly marl containing a good deal of iron. It has been burnt for lime in former days, but had a tendency to run to a slag if not carefully watched. In the long scar about the centre of the wood the following section is seen:—

Sections in Limekiln Wood, Whorlton Moor.

	Ft.	n.
Thin sandstone, well-bedded - - - - -	10	0
Shale (like Alum Shale), with doggers - - -	12	0
Rather pure ironstone - - - - -	1	0
Hard ferruginous marl - - - - -	25	0

Towards the west end of the wood the section consists of thin sandstone and shale as above, succeeded by—

	Ft.	In.
Ironstone, very hard and fossiliferous, containing *Myacites* sp., *Pholadomya Sæmanni*, *Ammonites* sp., *Belemnites*, *Terebratula trilineata*, and many other fossils, difficult to extract whole	1	3
Very hard marl, siliceous at base - - - -	4	9
	6	0

Between the faults at Scarth Nick nothing is seen of the Dogger, but it is exposed again along the north-west corner of the great escarpment, where it is about 4 feet thick.

Another fault brings this bed still further up the escarpment to Beacon Scar, where the following fine section is exposed:—

	Ft.	In.
Massive soft sandstone - - - - -	50	0
Carbonaceous shale with sandy partings - - -	15	0
Flaggy sandstone - - - - - -	2	0
Shale, like Alum Shale - - - - -	15	0
Thin, carbonaceous, gannister bed - - - -	2	0
Shale full of nodules, contains *Ammonites* in lower part -	5	0
Calcareous ferruginous bed with shaly parting - -	4	0
Alum Shale.		

Along Mount Grace Bank, and for a considerable distance up the valley above Osmotherley, there is no Dogger seen, and it certainly cannot be thick; for, on the west side above High Mill, Oolite Sandstone and Alum Shale are seen within a few feet of one another.

Nothing is seen of the Dogger east of Osmotherley owing to downwash and talus, but near the head of Oak Dale there is an opening marked "old limestone quarry" on the six-inch map, which may have been an old working of this bed.

In the old Alum Works near Thimbleby Lodge the Dogger is about 18 inches thick, presenting the same ferruginous calcareous character; but in a trial-hole at the scar over Thimbleby it consists merely of a few nodules in shale, and in the small hollows about Over Silton it is not seen anywhere. Near Kepwick at a trial-hole in Atley Bank the following section may be seen:—

		Ft.	In.	Ft.	In.
	Ferruginous sandstone			6	0
	Shaly sandstone			5	0
	Grey shale			2	6
The Dogger.	Thin band of ironstone	0	6		
	Shale	2	0		
	Hard ferruginous limestone	5	6	11	6
	Shale	1	6		
	Ferruginous limestone	2	0		

In the interior of the Moorland there are several outcrops of the Dogger, the finest of which is in the upper branch of the Rye close under Snilesworth Shooting Lodge, where a ferruginous limestone about 5 feet thick, passing at times into a calcareous ironstone, is seen in the bed of the stream; under which it sinks for about 50 yards, and then rises again some few feet above the river, having Alum Shale beneath it. A similar outcrop is seen in Arns Gill to the east, the Dogger being here from 2 feet to 3 feet 6 inches thick. The junction of the Lias and Oolite is seen again at High Farm, where there is a small inlier of the Alum Shale, but the calcareous bed is absent.

About the great faulted outlier of Borrowby there is no visible outcrop of the Dogger on the east side, but on the west it is comparatively clear. Close by Beacon Hill at the north end some 3 or 4 feet of ferruginous limestone is seen resting on Alum Shale, and from this point southward a similar bed may be found at intervals, slowly thickening in this direction, till at the hollow where the road crosses the hill at Cotcliffe Bank the Dogger is a ferruginous sandy limestone about 5 feet thick. Its outcrop continues clear till it begins to turn south-east, when the Drift creeps up the hill and obscures it. Around the little Oolite hill at Knayton the Dogger is similarly hidden.

Continuing along the main escarpment in the neighbourhood of Cowesby the Drift reaches just up to the base of the Oolites, and the Dogger is not seen, but an old slag heap not far from the Hall gives reason to suppose it was once worked there to a small

extent. Round the outlier north-west of Kirby Knowle it crops out in several places, particularly in Low Wood and near New Buildings, where it is a ferruginous limestone about 4 feet thick. At Knowle Hill and in the main escarpment close by it is well seen, a trial-hole in the latter place showing it to be a calcareous ironstone some 5 or 6 feet thick. From this point past West Acre Lodge to close by Boltby the outcrop is very clear, an adit close by the village showing that it retains much the same character. On all the outliers about here the Dogger may be seen in some part of them; about Feliskirk Hill it is a ferruginous limestone 6 to 8 feet thick, and has been worked as a limestone to a small extent on the north-west face of the hill. North and east of Boltby the gravel that is so abundant about here obscures the outcrop, but it reappears north of Tang Hall, where it has the same character, and where an adit has been made into it. Further south the position of the bed is fairly clear.

At Cleaves Quarries, where it has been largely worked and burnt for lime, it has a thickness of over 20 feet, as will be seen from the following details:—

Section at Cleaves Bank Quarry.

	Ft.	In.
Massive soft sandstone, very ferruginous at base	30	0
Blue clay and soft beds with calcareo-argillaceous balls	4	0
Massive false-bedded siliceous limestone	10	0
Thin band with *Ostrea*, *Pentacrinus*, and scattered pebbles, very pebbly at base	1	6
Oolitic limestone (base not seen	6	6

In the next quarry at the side of the Thirsk road the shaly band between the sandstone and the limestone is thicker, there being over 20 feet of it; the limestone becomes more pebbly in this direction, and beyond Hood Grange appears to thin out, or is only represented by a ferruginous sandstone. The outcrop here shows how irregular this bed is, for whereas on the north side of the valley at Hood Grange it has a considerable thickness, on the south side below Hood Hill, a distance of only 500 yards, it is not present, or is so thin as not to be traceable.

In the road between High and Low Kilburn there are some shales with thin ironstone nodules which may represent this bed, but it is too thin to be mapped anywhere in this area.

Throughout the Howardian Hills the Dogger occurs very irregularly, being an important rock in a few places, but in others thinning out, so that for long distances it disappears or is represented by only an ordinary sandstone.

At the western end of this range of hills the Dogger, which is here a massive ferruginous glance limestone and very hard, forms the fine feature of Beacon Bank above Husthwaite. Just south of this village it is thrown down by a fault, and cropping out in lower ground is exposed in a quarry below Highthorne, where the diagonal jointing of the rock similar to that at Peak is well shown; the rock is also seen at Providence Hill, beyond which it passes beneath the alluvium.

On the southern side of these hills the Dogger appears to have thinned out, for although the base of the Oolites makes a fairly good feature along part of its course this bed is not seen, nor is there any clear evidence of it till we reach the neighbourhood of Terrington, a distance of nearly 10 miles. About a mile west of this village there is the following section in the steep bank just below the trigonometrical station:—

	Ft.	In.
Rubbly bed of sandstone, with pebbles or concretions -	- 4	0
Ferruginous limestone, lower part not seen - -	- 7	0

At the village the Dogger either dies out, or is so thin as not to be recognisable; but a quarter of a mile to the south it is a foot thick and beyond this rapidly increases to as much as from 10 to 15 feet in thickness, making a considerable spread on the hill-tops about Mowthorpe. It is here quarried as a road material and forms quite a rocky scarp along the sides of that dale. To the south of this it is depressed by a fault, and crops out at a much lower level in Ox Pasture Wood and Bulmer Beck, but, rising again rapidly towards Stittenham, is seen along the upper edge of that wood.

There is a small inlier of this rock brought up by the fault north of Wiganthorpe House, which is seen on the roadside at Swinsey Carr, where a few feet of ferruginous sandstone, with fossils and the usual pebbly concretions, repose on a thin bed of impure ferruginous limestone.

Between Bulmer and Whitwell, although the base of the Oolite still continues to make a fine escarpment, this bed is not represented except by ferruginous sandstone with here and there a little ironstone.

In the gorge cut by the Derwent at Kirkham the Dogger is well seen on both sides of the valley. It has a thickness of about 12 feet, and consists mainly of ferruginous sandstone, which towards the lower part is more calcareous and very full of pebbles. It has been tried for ironstone on both sides of the valley, but never worked to any extent, the rock being apparently too poor to cover the cost of carriage to the furnaces.

In the railway bank at Castle Howard Station there is a band of rock which possibly represents the Dogger, although if it does it is very close to the Hydraulic Limestone. Mr. Hudleston* has found *Lingula Beanii* and *Discina reflexa* in this bed, together with *Myacites*, *Avicula*, and *Cardium*, and therefore he considers it to represent rather a lower horizon than the Dogger of Rosedale and the coast, but *Lingula Beanii* has been found well up in the Dogger in the Cleveland district, and therefore its evidence as a zone fossil is not of much value. In the wood to the south-west of the station the Dogger is well exposed, and may be followed along the bank for some little way. It caps the hill to the north of Crambe, forming a rather conspicuous outlier. On the east side

* Proc. Geol. Assoc., vol. iii p. 324. 1874.

of the Derwent the outcrop is equally easy to follow, the best sections being at the old adit in Kirkham Park, in the quarry above the Abbey, and at Spy Hill.

At the latter place the strata are thrown up by a large fault, so that the outcrop is shifted considerably further to the east, in which direction the Dogger becomes much thinner and is scarcely recognizable. It is, however, well exposed on the long tongue of Oolite to the south at Gally Gap, and also in Leavening Beck, and near Acklam; beyond which it cannot be traced as a separate bed, although fragments of the rock are seen at several places, particularly on the hillside south of Kirkby Underdale. At all of these places the Dogger is very ferruginous, and contains the usual pebbles or concretions.

In South Yorkshire the Lower Oolites form a continuation of those in Lincolnshire and beyond, and with these they should be compared, rather than with those in the northern part of the county, which, although similar in some respects, undergo considerable alteration during their overlap by the Cretaceous beds.

The great Estuarine Series, which forms so striking a feature in North Yorkshire, has almost entirely disappeared, and the remaining beds, chiefly marine, occupy a narrow strip at the foot of the Wolds southward from Market Weighton, which is never more than about half a mile in breadth.

These beds first appear rather more than a mile to the north of Sancton; they are overlapped by the Chalk in the valley to the south of the village, but appear again about Newbald, and continue thence uninterruptedly to the Humber, where, however, they are a good deal obscured by superficial deposits.

They are, in this region, composed mostly of clays with some shaly sandstone, and at the base a thin fossilferous bed, which may, to a certain extent represent the Dogger.

Throughout the whole line of outcrop there is no very satisfactory section, the best, however, being that in the beck just above the mill at Ellerker, where the following thickness was measured:—

Section in the Basement Beds of the Oolite at Ellerker.

	Ft.	In.
Hydraulic limestone	2	6
Yellow sandy shale	6	0
Calcareous sandstone with fossils, *Ostrea*, &c.	0	3
Dark shale (Lias).		

The trial-shafts south of Ellerker, from the lack of marked lithological divisions, do not give much insight into these beds. It is probable that there are somewhere about 20 feet of measures, more or less, between the Cave Limestone and the Lias.

The boring near Brantingham Grange* went through 23 ft. 8 in. of shale and stone between the Lias and the calcareous beds which belong to the limestone; but whether the 2 ft. 8 in. of blue ferruginous stone at the base alone represents the Dogger, or

* See page 122.

whether some of the strata above should be included in the subdivision is doubtful.

These strata, to which the name "Basement Beds" has been given in Lincolnshire, are, however, better exposed on that side of the Humber; where they form the crest of the escarpment known as The Cliff.

*Fossils of the Dogger.**

CŒLENTERATA.

Montlivaltia convexa, *Phil.*
—— sp. (near to M. lens, *M'Edw.*)
Thecosmilia gregaria, *M'Coy.*
—— sp.

ECHINODERMATA.

Acrosalenia, sp.

CRUSTACEA.

Eryma (Glyphæa) Birdii, *Bean,*† *MS.*
Glyphæa Prestwichi, *Carter, MS.*

BRACHIOPODA.

Acanthothyris (Rhynchonella) Crossi ?, *Walker.*†
Discina reflexa, *Sow.*†
Lingula Beanii, *Phil.*†
Rhynchonella cynocephala, *Rich.*†
—— obsoleta, *Sow.*
—— subobsoleta, *Dav.*
Terebratula trilineata, *Y. & B.*†

LAMELLIBRANCHIATA.

Avicula Münsteri, *Goldf.*
—— substriata, *Münster.*†
Gervillia Hartmanni, *Goldf.*
—— lata, *Phil.*
—— tortuosa, *Phil.*
Hinnites abjectus, *Phil.*
—— tumidus ? *Ziet.* (velatus, *Goldf.*)
Lima cardiiformis, *Sow.*
—— pectiniformis, *Schlot.*
—— toarcensis, *Desl.*†
Ostrea flabelloides, *Lam.*†
—— solitaria, *Sow.*
—— Sowerbyi, *L. & M.*†
—— spatiosa, *Bean, MS.*
Pecten arcuatus. *Sow.*
—— articulatus, *Schlot.*†
—— demissus, *Phil.*
—— disciformis, *Schüb.*†
—— lens, *Sow.*
—— virguliferus, *Phil.*
Perna isognomoides, *Stahl.*†
Pteroperna plana, *L. & M.*
—— striata, *Bean, MS.*
Astarte elegans, *Sow.*
—— excavata, *Sow.*
—— minima, *Phil.*
—— paupertina, *Bean, MS.*
Cardium gibberulum, *Phil.*
—— incertum, *Phil.*
—— striatulum, *Sow.*
Ceromya bajociana, *d'Orb.*
Cucullæa cancellata, *Phil.*
—— reticulata, *Phil.*
Cypricardia cordiformis, *Desh.*
—— rostrata, *Sow.*
Cytheræa (Cyprina) dolabra, *Phil.*
—— plana, *Bean, MS.*
Goniomya angulifera, *Sow.*
Gresslya abducta, *Phil.*
Isocardia cordata, *Buck.*
Leda anglica, *d'Orb.*
—— lachryma, *Sow.*
—— rostralis, *Lam.*†
Lucina despecta ?, *Phil.*
Macrodon hirsonensis, *d'Arch.*
Modiola cuneata, *Sow.*
—— furcata ?, *Goldf.* (M. aspera, *Phil.*)
—— imbricata, *Sow.*
—— sowerbyana, *d'Orb.*
—— ungulata, *Y. & B.*
Myacites æquatus, *Phil.*
—— dilatus, *Phil.*
Mytilus cuneatus, *Phil.*
Nucula variabilis, *Sow.*
Opis similis, *Sow.*
Pholadomya Heraulti, *Ag.*
—— Sæmanni, *L. & M.*
Quenstedtia lævigata, *Phil.*
—— oblita, *Phil.*
Sowerbya triangularis, *Phil.*
Tancredia axiniformis, *Phil.*
Trigonia denticulata, *Ag.*
—— formosa, *Lyc.*
—— sharpiana, *Lyc.*
—— spinulosa, *Y. & B.*
—— v-costata, *Lyc.*

* Species found only in the "Dogger Sands" are excluded from this list.

† It is doubtful whether these species are found in the Dogger proper or not. In many cases it is not stated whether species have been found in the Dogger itself or in the Blea Wyke Beds below. Also at the inland localities these latter beds, if they exist, have not been separated.

Scaphopoda.

Dentalium elongatum, *Goldf.*
Dentalium entaloides, *Desl.*

Gasteropoda.

Actæon Sedgvici, *Phil.*
Actæonina glabra, *Phil.*
—— humeralis, *Phil.*
—— mitræformis, *Brauns.**
—— sp.
Alaria hamus, *Desl.* var. Phillipsii, *d'Orb.*
——pseudo-armata, *Hud.*
—— sublævigata, *Hud.*
—— unicarinata, *Hud.*
Amberleya biserta, *Hud.*
Cerithium Beanii, *L. & M.*
—— Leckenbyi, *Hud.*
—— muricatum, *Sow.*
—— turris ?, *Hud.*
—— vetustum, *Phil.*
Chemnitzia coarctata ?, *Desl.*
—— lineata, *Sow.*
Cloughtonia (Phasianella) cincta, *Phil*
Fibula (Cerithium) canina, *Hud.*
Littorina biserta, *Phil.*
—— Phillipsii, *L. & M.*
—— unicarinata, *Bean.*
—— sp.
Natica adducta, *Phil.*
Natica cincta, *Phil.*
—— proxima, *Hud.*
—— punctura, *Bean.*
Nerinæa cingenda, *Phil.*
—— cingenda, *Sow.*
Nerita costulata, *Desh.*
—— minuta, *Sow.*, var. tumidula, *Phil.*
—— pseudo-costata, *d'Orb.*
Neritopsis bajocensis, *d'Orb.*
—— lævigata, *Phil.*
Onustus ornatissimus, *d'Orb.*
—— pyramidatus, *Phil.*
Pleurotomaria anglica, *Sow.*
Pseudalaria (Trochus) jugosa, *Bean.*
Purpurina elaborata, *Bean.*
Trochotoma calix, *Phil.*
Turbo funiculatus, *Phil.*
—— granatus, *Hud.*
—— lævigatus, *Sow.*
—— melanioides, *Bean.*
—— sp.
Turritella opalina, *Quenst.*, var. canina, *Hud.*
—— quadrivittata, *Phil.*

Cephalopoda.

Ammonites Murchisonæ, *Sow.*
Belemnites giganteus, *Schlot.*
Nautilus lineatus, *Sow.*

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* It is doubtful whether these species are found in the Dogger proper or not. In many cases it is not stated whether species have been found in the Dogger itself or in the Blea Wyke Beds below. Also at the inland localities these latter beds, if they exist, have not been separated.

CHAPTER VI.

THE LOWER OOLITES—*continued.*

THE LOWER ESTUARINE SERIES.

THE great series of Estuarine beds, which form the chief part of the Lower Oolites and which have so large a development in Yorkshire, may be said to constitute an Oolitic coal-field resembling on a small scale the more important measures of Carboniferous age. They consist of irregular alternations of sandstone and shale containing plant remains, thin seams of coal and occasionally a little ironstone, suggesting a freshwater or estuarine origin. Over a portion of this area these beds are capable of being separated, as we mentioned above, into three distinct horizons by the Grey Limestone and the Millepore Bed; but as the former of these marine bands dies out in the extreme south while the latter disappears to the north it is not always possible to retain these divisions. They are, however, very convenient as far as they go; we therefore propose to use the terms Lower, Middle and Upper Estuarine Series respectively, where we are able to make out the intervening bands, and to speak of them in a general way as Estuarine Series when these beds are not recognizable.*

There has been some confusion among the older authors in the nomenclature of the Estuarine Series of the Lower Oolites from the fact of the marine bands forming the respective divisions not being always recognized. W. Smith used the terms "Coaly Grit, Sandstone and Sand" for all the beds between the Cornbrash and the Lias without making any divisions between them. Young and Bird recognized the position of the Grey Limestone, and that the beds above were somewhat different in character from those below; to the latter, which they treated as one formation, they gave the name "Sandstone Shale and Coal." Prof. Phillips described the lower part of this series as the "Lower Sandstone Shale and Coal" or the "Lower Carbonaceous Sandstone and Shale," but he was at first a good deal confused as to the respective positions of the Grey Limestone and Millepore Bed, consequently the plant remains from Gristhorpe, which are really in the Middle Estuarine Series, are mentioned as occurring in the upper division, while many apparently from the same horizon further north are given from the lower series. This error was,

* These names do not imply that the beds in question are of the same age as those similarly named in the Midland counties, although some of them may be contemporaneous.

however, corrected in the last edition of his work, the Gristhorpe plants being placed in the "Middle Shale,"* although it is not very clear whether some species from Staintondale may not still be erroneously included in the Lower Series. Dr. Wright classed the whole of the arenaceous lacustrine deposits below the Grey Limestone under the term "Lower Sandstones and Shales," apparently considering, as Williamson had done, that the strata seen on the coast between it and the Millepore Bed were merely a local episode not represented elsewhere. Mr. Hudleston correctly divides the Estuarine beds into three series under the terms "Lower, Middle, and Upper Shale, and Sandstone."

Synonyms.—"Lower Carboniferous Series" (part), Smith;† "Sandstone Shale and Coal" (part), Young and Bird, Geol. of the Yorksh. Coast, p. 109, 1822; "Coal formation,"‡ (part) Sedgwick, Ann. of Phil., ser. 2, vol. xi. p. 345; "Lower Sandstone Shale and Coal," or "Lower Carbonaceous Sandstone and Shale" (part), Phillips, Geol. of York, pp. 33 and 153, 1829; "Lower Sandstone and Shale," Williamson, Trans. Geol. Soc., ser. 2, vol. 5, p. 235, 1837; "Lower Sandstones and Shales" (part), Wright, Quart. Jour. Geol. Soc., vol. xvi. p. 30, 1860; "The Lower Shale and Sandstone," Hudleston, Proc. Geol. Assoc., vol. iii. p. 306, 1874; "Lower Estuarine Series," Memoir of the Geol. Survey, Expl. of 95, S.W. and 95, S.E. 1880.

Of the three series of Estuarine beds the lowest is the most arenaceous; it contains thick and important beds of sandstone which can often be traced for considerable distances, although they are not constant enough to be relied upon as geological horizons. They vary somewhat in their passage across the country, but like the higher series are most arenaceous in the north and west. About the middle of the series there is a well-marked marine band known as the Eller Beck Bed, which we will describe presently. With this exception the series as far as we know does not contain any marine shells, but remains of land plants are very abundant, although the number is not quite so large as in the series above. In fact but for the rich store of plants which have been obtained from the Estuarine beds of the Yorkshire coast we should know little of the ancient vegetation of the Oolitic period. Many of these have formed the type specimens with which the Jurassic flora of other localities have been compared.

The fact that these sandstones and shales contained "vegetable bodies" was noticed by many of the older writers, but the first attempt to figure any of the specimens was by Young and Bird in 1822, who, in the "Geol. of the Yorksh. Coast" give imperfect drawings of a few of the most remarkable from the valley of the Esk and the Whitby Coast, but showing no details of structure, and without either names or descriptions. In Prof. Phillip's description of the Yorkshire Coast, 1829 and 1836, many species are named and figured, but not described.§ Since then the numerous species of this remarkable flora have been figured and described

* Prof. W. C. Williamson was the first to point out the correct position of the beds at Gristhorpe.

† Smith quoted by Williamson, Trans. Geol. Soc., ser. 2, vol. v. p. 229. 1837.

‡ Includes the whole of the Lower Oolites.

§ Many species have retained the MS. names given them by Bean.

by Brongniart, "Végétaux Fossiles," 1828; Lindley and Hutton "Fossil Flora," 1833; Göppert, "Systema Filicum fossilium"; Sternberg, "Flora der Vorwelt"; De Zigno, "Flora Fossilis formationis Oolithicæ," 1856–73; Bunbury, Quart. Journ. Geol. Soc., vol. vii. p. 179, 1851; Leckenby, Quart. Journ. Geol. Soc., vol. xx. p. 74; and again by Prof. Phillips in 1875, who in the 3rd edition of the "Geology of the Yorkshire Coast" analysed the determinations of previous authors and brought the subject fairly up to date at that time. In recent years, however, the subject of Fossil Botany has undergone some important changes, and many of the species have been revised by Nathorst, Lebour, and others.* From these accounts this and the succeeding lists of plants have been compiled. The species given in this list are said to be from the "lower sandstone and shale," but it is possible, as the lower and middle series were formerly considered as one, that a few of the species may belong to a higher horizon.

List of Plants from the Lower Estuarine Series.

CRYPTOGAMIA (EQUISETACEÆ).†

M	*Equisetum columnare*, Br.	Hayburn, Staintondale High Whitby.
M	*Lycopodites falcatus*, L. & H.	
M	*Phyllotheca* (*Equisetites*) *lateralis*, Phil.	Hayburn Wyke.

CRYPTOGAMIA (FILICES).

M	*Acrostichites princeps*, Presl.	
	Asplenium (*Pecopteris*) *whitbiense*, Br.	Hayburn, Whitby.
	Dicksonia (*Sphenopteris*) *hymenophylloides*, Br.	Hayburn.
	Marzaria Simpsoni, Phil.	Hawsker.
	Pachypteris (*Dichopteris*) *lanceolata*, Brong.	Saltwick, Egton Moors Hayburn.
M	*Pecopteris cæspitosa*, Phil.	Hayburn.
M	„ *curtata*, Phil.	Staintondale.
M	„ *dentata*, L. & H.	
	„ *haiburnensis*, L. & H.	Hayburn.
	„ *inconstans*, Phil.	Hayburn.
M	„ *lobifolia*, Phil.	
	„ *polydactyla*, Göpp.	Hayburn.
	Sphenopteris affinis, Phil.	Hayburn.
	„ *arbuscula*, Phil.	Hayburn, Staintondale.
	„ *arguta*, L. & H. *denticulata*, Br.	Hayburn.
	„ *athyroides*, Brong.	Saltwick ?.
	„ *crenulata*, Br.	Hayburn.
	„ *dissocialis*, Phil.	Hayburn, Saltwick.
	„ *Jugleri*, Ettingsh.	Staintondale.
	„ *muscoides*, Phil.	Hayburn.
	„ *quinqueloba*, Phil.	Hayburn, Staintondale.
	„ *socialis*, Phil.	Hayburn, Saltwick.
M	*Tæniopteris vittata*, Br.	Saltwick.
	Thyrsopteris maakiana, Heer.	

M Those marked thus occur also in the Middle Estuarine Series.

* See Williamson, Linn. Trans., vol. xxvi., p. 663, 1870; Carruthers, Ibid., p. 675; Lebour, Catalogue of the Hutton Collection of Fossil Plants [at Newcastle-upon-Tyne], 1878; Nathorst, Öfv af Kongl. Vetens. Akad. Forhand., 1880, No. 5, p. 23, and No. 9, p. 33. Stockholm, 1881.

† Vertical stems of *Equisetites* are common throughout the northern moorlands.

GYMNOSPERMÆ (CYCADACEÆ).

M *Anomozamites lindleyanus*, Sch. (*Pt. minus*, L. & H.)	
M *Cycadites zamioides*, Leck.	Whitby.
M *Otozamites acuminatus*, L. & H. - -	Hayburn.
„ *distans*, Nathorst. - - -	Whitby.
„ *gracilis*, Phil. - - -	Hayburn.
„ *gramineus*, Phil. - - -	Saltwick, Whitby.
„ *graphicus*, Bean. - - -	Hayburn.
„ *lanceolatus*, Phil. - - -	Whitby.
„ *latifolius*, Phil. - - -	Saltwick.
„ *obtusus*, L. & H. - - -	Hayburn.
„ *parallelus*, Phil. - - -	Whitby.
„ *tenuatus*, Bean. - - -	Hayburn.
Podozamites (*Zamites*) *lanceolatus*, L. & H. -	Hayburn, Whitby.
Solenites furcata, L. and H. - - -	Hayburn.
Williamsonia gigas, L. & H. - - -	Whitby.
„ *hastula*, Bean. (*Pt. pectinoideum*, Ph.)	Hayburn, Saltwick.

GYMNOSPERMÆ (CONIFERÆ).

Araucaria Phillipsii, Carr. - - -	Hayburn.
M *Brachyphyllum mammillare*, Br. - - -	Hayburn, Whitby.
„ *setosum*, Phil. - - -	Hayburn.
M *Cryptomerites divaricatus*, Bunbury.	
Ginkgo whitbiensis, Nathorst. - - -	Whitby.
Taxites brevifolius, Nathorst. - - -	Whitby.
M *Thuytes expansus* ?, Sternb. - - -	Egton, Saltwick.

M Those marked thus occur also in the Middle Estuarine Series.
U Occurs also in the Upper Estuarine Series.

In the above list of plants only thirteen species pass up into the Middle Estuarine Series and only one into the Upper Estuarine Series; showing that although the several series represent a more or less continuous deposit only interrupted by slight incursions of marine conditions, nevertheless large intervals of time must have interlapsed between the several periods during which the flora was able to undergo so considerable a change. Over the northern moorlands, where the Millepore Bed dies out, and the Lower and Middle Estuarine Series consequently form one consecutive deposit, it is possible that the species common to both may be greater, but we have no evidence on this point, these rocks not having been as yet sufficiently examined with this view, nor have scarcely any plants been obtained from the inland sections.

In the Lower Estuarine Series there are no *Algæ* nor any purely marine plants; but, as we should expect in beds formed under estuarine conditions, marsh-loving plants such as *Equisetaceæ* abound, these in fact being more common on certain horizons than all the other species put together. So plentiful are these plants in some places that they contribute largely if not entirely to the formation of thin seams of coal. They frequently occur in a vertical position, and rooted in the soil in which they grew; this latter sometimes forming the valuable underclays we have alluded to elsewhere. It was formerly supposed that these plants floated into the position in which they are found, the superior gravity of their roots keeping them in an erect position;*

* Williamson, Trans. Geol. Soc., 2nd ser., vol. v. p. 230; also Phillips, Geol. of the Yorksh. Coast, 2nd Ed. p. 66, and 3rd Ed. p. 143.

but if this was the case we should not find these continuous bands of clay penetrated by innumerable rootlets. For this reason it is clear that the coal seams were formed by the gradual decay of the plants in the place where they grew, and are not the result of drifted vegetation.

The most plentiful of all the Jurassic plants however are the ferns; of which there are, according to Mr. Etheridge, no less than 53 species in the different Estuarine Series. Of these the genus *Pecopteris* is very plentiful in both the Lower and Middle Series. Numerous species of *Sphenopteris* also occur in the Lower Series, but no species of *Phlebopteris* which is so abundant in that above. Of the Cycads the Lower Estuarine Series is remarkable for the abundance of the genera *Otozamites* and those allied to *Zamites*; in the Middle Estuarine Series these are rarer and we have a preponderance of the genus *Pterophyllum*.

The Lower Estuarine Series are first seen on the coast south of Scarborough where they form the outer part of the scars opposite Yons Nab,* and Carnelian Bay. At the first of these places there are two or three reefs of this sandstone, but they are only exposed at very low water. In Carnelian Bay these beds have their largest exposure, being brought up by the fault which traverses the bay, and the course of which is well seen by the disturbance it causes to the sandstones on either side. At neither of these places is there a very great thickness exposed, but the rocks appear to have become excessively hard, and well able to withstand the force of the sea.

North of this these beds do not come above sea-level till we reach the northern side of Cloughton Wyke, a distance of over six miles, where they again appear and continue along the lower part of the cliff by Hayburn Wyke and Staintondale to Blea Wyke. Above the Dogger at this place there is a clear section showing the whole of the Lower Series which is here divided into two portions by the thin marine band known as the Eller Beck Bed. The section is as follows† :—

The Lower Estuarine Beds, Blea Wyke.

	Ft.	In.		Ft.	In.
Massive false-bedded sandstone, very ferruginous	60	0			
Light sandy shale	8	0			
Hard white stone	0	9			
Dark shale with underclay	2	0			
Shale with carbonaceous bands	20	0		111	1
Hard white stone	1	0			
Shale	9	0			
Coal Seam, very impure	0	4			
Rubbly flaggy sandstone	10	0			
Thin flaggy sandstone resting on a few feet of soft shale enclosing thin bands of ironstone			Eller Beck Bed	15	0

* Corruption of the word Yown or Yoon, signifying oven.

† The following details are mainly from the descriptions given by Mr. Barrow in the Geological Survey Memoirs; a few relating to the interior dales are by Mr. Reid.

	Ft.	In.	Ft.	In.
Shales, soft and light coloured, with a band of ferruginous nodules containing plant remains	20	0		
Carbonaceous shale	1	0		
Shale, rather sandy	20	0		
Carbonaceous shale	2	0		
Very hard sandstone	2	0		
Shale, soft and soapy to the touch	8	0		
Sandstone, somewhat flaggy	5	0		
Shale	5	0		
Sandstone	3	0		
Dark shale	3	0		
Shale with thin bands of very hard stone	30	0	159	11
Coal Seam	0	6		
Underclay	2	0		
Soft ferruginous sandstone, with vertical stems of plants, probably *Equisetites*, often 5 feet high	12	0		
Shale, soft and light coloured	4	0		
Coal Seam	0	2		
Sandstone, soft and rubbly	2	0		
Coal Seam	0	3		
Shale, dark coloured	6	0		
Sandstone, coarse grained, ferruginous, and false bedded	24	0		
Shale, dark coloured	10	0		
Total			286	0

Dogger series, &c. Hard and ferruginous Sandstone.

In the Staintondale cliffs the upper portion of this series is in most places hidden by the débris and fallen blocks from the cliff above; the beds below the Eller Beck Bed are however much better seen, and form the lower cliff from Iron Scar south of Hayburn Wyke to Blea Wyke. From a general view of these cliffs it is seen that sandstone predominates in the upper part, shale in the lower.*

At Hawsker where the Grey Limestone comes close to the edge of the cliff, there are about 285 feet of Estuarine beds between it and the Alum Shale, while the thickness between the Eller Beck Bed and the Dogger is only about 100 feet. There is a very clear section here, but as the Millepore Bed has died out, the Lower and Middle Estuarine Series cannot be separated; consequently north of this we have to treat them as one formation. In these cliffs two thin coal seams are seen just above the Dogger, but they die away before reaching Whitby, although they were proved in the boring given below. Between Hawsker and Whitby the variations in the strata are very remarkable, thick lenticular beds of sandstone coming in and frequently cutting out the shales that were previously deposited. These false-bedded sandstones are very rich in plant remains and soft jet. Beyond Whitby the Estuarine Series are not so well exposed from the thick covering of Boulder Clay, but a good general idea of the strata below the Grey Limestone may be formed from the following detailed account of a boring put down in 1821, by

* It has been supposed that the lower cliff is a repetition of the upper one slipped down. This is not the case. See page 418.

Col. Wilson, on the south bank of the Esk, opposite the village of Ruswarp.*

	Ft.	In.
Soil and gravelly clay (alluvium) - - - - -	22	0
Blue metal (sandy shale) - - - - -	10	0
Black stone (bituminous shale) - - - - -	2	0
Grey metal (grey shale) - - - - -	3	0
Brown post (brown sandstone) - - - - -	1	0
Grey metal - - - - - - - - -	1	0
Yellow gullety stone (soft sandstone) - - -	10	0
Grey metal stone with post girdles (hard nodules) - -	8	0
Yellow post (yellow sandstone) - - - - -	6	0
Blue metal - - - - - - - - -	15	0
Coal - - - - - - - - - -	0	4
Blue metal with skares of coal (bituminous shales) - -	11	8
Yellow skamy post - - - - - - -	2	0
Blue metal - - - - - - - - -	2	6
Black stone with a mixture of coal - - - -	0	6
Blue metal - - - - - - - - -	3	6
Coal - - - - - - - - - -	0	6
Grey post with water - - - - - - -	3	4
Whin (ironstone) - - - - - - - -	0	8
Grey post - - - - - - - - -	3	0
Blue metal - - - - - - - - -	8	0
Blue metal stone (blue schistose sandstone) - - -	3	0
Grey metal - - - - - - - - -	3	0
Grey and white post - - - - - - -	7	0
Grey metal with post girdles - - - - - -	13	8
Blue metal stone - - - - - - - -	2	0
White post with metal partings - - - - -	18	4
Grey metal with skares of coal - - - - -	3	0
Grey metal stone - - - - - - - -	4	0
Whin - - - - - - - - - -	1	6
Grey metal with metal partings - - - - -	10	6
Whin - - - - - - - - - -	1	0
Grey post with metal partings - - - - -	18	0
Grey metal - - - - - - - - -	2	0
Foul coal - - - - - - - - -	0	5
Grey metal with post girdles - - - - - -	11	7
Grey post - - - - - - - - -	3	0
Grey metal stone - - - - - - - -	14	0
Coal - - - - - - - - - -	0	4
Grey metal - - - - - - - - -	4	2
Coal - - - - - - - - - -	0	11
Grey metal - - - - - - - - -	6	0
Grey post - - - - - - - - -	4	7
Whin (this and the preceding rock appear to form the "Dogger") - - - - - - -	1	6
	247	6

Below this the boring was carried on nearly 100 feet further into the Alum Shale.

The Grey Limestone crops out in the bank about 30 feet above the site of this boring, consequently the total thickness of the Estuarine Series below that bed is about 270 feet.

Some distance to the west of Whitby in Raithwaite Gill fine sections of the sandstone and shales of the Estuarine Series may be seen, which are very picturesque but not of much interest geologically. From this point to Warsett Hill, near Saltburn, all

* Young and Bird, Geol. of the Yorkshire Coast. 2nd edition, p. 124.

the higher points in the cliff are capped with beds of this series, but only in one place do strata so high as the Eller Beck Bed come on. In the clear and easily-accessible cliffs north-east of Goldsborough the sandstones and shales can be readily examined; several of the shales here being good fire-clays, though no coal is seen.

Inland there are good exposures in the various streams south and west of Mulgrave Woods. At the head of Borrowby Dale, and again a little north of Scaling, a thick bed of sandstone occurs close under the Grey Limestone, forming in the latter case bold and picturesque scars; while beds considerably lower in the series can be seen by following down Rousby Beck and Easington Beck. Liverton and Hagg Becks, which unite to form Kilton Beck, give a remarkably fine series of sections of the strata between the Eller Beck Bed and the Grey Limestone Series, forming some of the most beautiful stream scenery in the district; here again a thick mass of sandstone occurs close beneath the latter bed. A complete section from the Dogger to the Eller Beck Bed and some distance above is seen just south of Lofthouse and again in the beck between Hagg Hole and Mill Holme.

Except the sandstones seen in quarries, there are no good sections about either Eston or Upleatham hills, but borings in the former have given a complete section of these beds. In the great escarpment south of Guisbrough the old Alum quarries have exposed the lower strata very well, and bring out strongly the rapid changes in the Estuarine Series. At Belman Bank Quarry the basement beds are for the most part shaly, while about Highcliff an imposing mass of sandstone marks the junction of the Lias and Oolite.

Along the valley of the Esk the Estuarine Series are brought down by the deep synclinal which ranges along the hills to the north, so that as a rule the beds crop out at a higher level on the south side than on the north. Throughout a great part of the dale the strata are obscured by Drift, and are principally interesting on account of the old coal workings and building stones they contain, to which we will refer presently.

In Commondale one of the fire-clay beds is worked for making drain pipes of large size and a superior class of perforated bricks. There is a nearly complete section in this neighbourhood, but we were unable to identify the Eller Beck Bed.

In the Grosmont district there is about 30 feet above the Dogger, a great mass of sandstone, sometimes as much as 60 feet thick, which makes a very bold feature along both sides of the valley. This bed is remarkably persistent, and is the source of a considerable part of the building stone of the district, the famous Aislaby quarries being in the lower part of it. To the south it passes through Crag Cliff Wood and up Eller Beck, where there is a complete section of all these beds, though there is no point of special interest about them. The sandstones are, for the most part, very felspathic, which does not permit their resisting

much pressure, and, when this is the case, renders them unfit for building purposes.

A second boring for coal, put down by Col. Wilson, in 1821, is of some interest as showing the character of the Estuarine Series at the head of Little Beck.

*Boring at Maybecks, half a mile south of Falling Force.**

		Ft.	In.
	Soil and loose stones (alluvium)	4	0
	Strong brown post (brown sandstone)	13	0
	Blue metal and metal stone with post girdles (blue shale, schistose sandstone with hard nodules)	57	0
	Coal	0	4
	Grey metal stone (grey schistose sandstone)	27	0
	Strong post with a mixture of whin (sandstone with ironstone)	4	6
	Grey metal (grey shale)	1	6
	Dark blue metal (blue shale)	0	10
	Grey post (grey sandstone)	6	0
	Grey metal with post girdles (grey shale with nodules)	6	0
	Grey metal with skares of coal (bituminous shale)	3	0
	White post (white sandstone)	3	0
	Grey metal	1	2
	Coal	0	5
	Grey metal stone	5	0
	White post with water	1	6
	Soft white post	3	0
	Grey metal stone	3	3
	Black stone with a mixture of coal (bituminous shale)	0	6
	Blue metal and metal stone	7	0
	Strong white post	1	0
	Blue metal with skares of coal	4	6
	Grey post with metal partings (grey sandstone with seams of shale)	17	6
	Whin (ironstone)	0	4
	Grey post with partings	6	0
	White post with a mixture of whin	2	0
	Dark blue metal	5	0
	Whin	0	6
	Dark blue metal with skares of coal	1	9
	Grey metal stone	5	6
	Grey post with a mixture of whin	35	7
	Grey metal	5	6
The Dogger ?	Limestone	3	0
	Grey metal stone	6	0
	White post	3	10
		246	0

The site of this boring is said to have been 530 feet above sea-level, and about 100 feet below the "blue limestone," so that the Estuarine Series at this point are over 300 feet in thickness.

Over the Rosedale Moors the Estuarine Series covers the greater part of the higher ground surrounding the deep valleys which intersect these moorlands. There are about 280 feet of sandstones and shales with occasional fire-clays and thin coals between the Dogger and Grey Limestone Series in this district.

* Young and Bird, Geol. of the Yorkshire Coast. 2nd edition, p. 122.

Drift wood, which has frequently been converted into an inferior kind of jet, is abundant, and ferns often occur, though there is a curious scarcity of other fossils. No freshwater shells have yet been found in this district, but upright *Equisetites* are sometimes seen in the fire-clays and sandstones. The sandstones continually change or die out, so that no bed can be traced for any great distance. There is often a thick bed, making a distinct feature, a short height above the Dogger, and sometimes cutting into the Dogger, but neither this nor any other bed is to be trusted as making a definite horizon. Unfortunately, in this area there is a dearth of clear exposures of any magnitude, and only one of the pit sections has been preserved by which we can obtain a general idea of the thickness and character of the beds.

At the Castleton Road shaft of the Rosedale East Mines a continuous section from the Grey Limestone to the Dogger was laid open, and Mr. Roscamp has given full details, of which the following is an abbreviated statement*:—

		Ft.	In.
	Surface matter	2	6
[Grey Limestone Series.]	Grey shale	5	8
	Freestone	3	2
[Estuarine Series]	Grey and blue shale, and post, with coal, &c.	265	8
[Dogger.]	Freestone	10	0
	Dark shale	4	6
	Ironstone (blue)	11	0
	Total	302	6

Towards the west of this area it is very noticeable that the strata, as a rule, are more arenaceous, the sandstones forming by far the larger part of the Estuarine Series. The section under Burton Head, where the Alum Shale is succeeded by 110 feet of sandstone with mere partings of shale, shows this very well; the sandstone giving a very bold outline to the escarpment. On the edge of Ingleby Moor there is a very large quarry in this sandstone, but in Bilsdale these beds are generally not well developed, although there is a very bold crag of the thick sandstone in Tripsdale; and, on the west side of the dale, just above Helm House, where the uppermost part of the bed is more even and finer grained, it was once quarried extensively and furnished the stone from which Rievaulx Abbey was built.

Along the north-west escarpment there are about 250 feet of strata between the Dogger and the Grey Limestone Series consisting principally of massive and shaley sandstones with very little real shale, the beds here being much more arenaceous than they are further west. Mr. Winch has preserved the record of an old boring on Osmotherley Moor which gives some little insight into these beds, and shows the great thickness of some of the sandstones; but as its exact position is unknown it is not of much value.

* See Geology of Eskdale, Rosedale, &c., (Memoir of the Geol. Survey), p. 28.

*Boring on Osmotherley Moor.**

	Ft.	In.
Freestone	30	0
Blue plate	12	0
Red grit	6	0
Soft blue plate	2	0
Coal	0	6
Freestone	120	0
Total	170	6

After sinking to this depth they bored 150 feet further, and passing through many bands of sandstone and shale, seem to have left off in some soft white freestone, but as they kept no good account the details are doubtful. If they commenced just below the Grey Limestone Series, it would give the depth of the well-known Moor Coal as a little more than 50 feet below that series, and according to this boring there should be some 320 (!) feet of these estuarine beds, but as the whole is seen in the face of the escarpment to be clearly not more than 270 feet there must have been some mistake in the boring account, or else this coal does not represent the Moor coal at all, but is the thin upper seam, which was also found in the country to the south at Birdforth.

South of Osmotherley these beds form the lower part of the escarpment, but there is not much to notice about them beyond that they contain thick beds of sandstone which form the prominent nabs near Kepwick and Boltby.

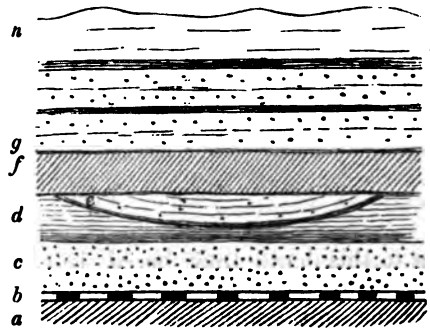
In the neighbourhood of Coxwold and throughout the Howardian Hills we are again able, from the coming in of the Millepore Bed, to divide the Estuarine Series into three definite horizons. In this region the whole of the series is very much thinner, and there does not appear to be more than 200 feet of strata altogether between the Dogger and the Grey Limestone, while below the Millepore Bed, that is the Lower Estuarine Series proper, there is not more than about 120 feet. In the neighbourhood of the Derwent, as we shall see presently, there are even less, and in the extreme south-east, just before they are lost below the overlap of the Chalk, they have almost thinned out altogether.

The beds are on the whole softer, that is, instead of consisting of shales and strong sandstones, they are composed mostly of beds of clay alternating with soft sandy rock, consequently there are few good features except quite at the base. The sandstone in the lower part is quarried at a few places, but this appears to be the only rock except the marine beds capable of being worked. A great part of the series in very clayey, but sandy beds come in again towards the top; these latter are usually very false-bedded and contain ferruginous streaks and thin beds of ironstone as may be seen in a sand pit at Ganthorpe.

* Winch, Trans. Geol. Soc., vol. v. p. 551.

FIG 10.

Sandstone Quarry, Cross Hill, Ganthorpe.



h. Thin flaggy ferruginous beds becoming calcareous in the upper part.
g. Sand horizontally stratified.
f. Sand with inclined stratification.
e. Ferruginous band.
d. Thin flaggy ferruginous bed.
c. Sand.
b. Ironstone nodules.
a. Interbedded coaly shales and sands.
(Total thickness exposed about 20 feet.)

On either side of the Derwent at Kirkham there are two shafts which were sunk with the intention of working the ironstone of the Dogger. These show that the Lower Estuarine Series is here reduced to about 100 feet in thickness.

Shaft at Mount Pleasant, near Castle Howard Station.

		Ft.	In.
Millepore Bed	Limestone	20	8
Estuarine Beds 38 ft. 0 in.	Hard blue shale	4	0
	White sandstone	9	0
	Ironstone	0	8
	Nodules	0	4
	Red sandstone	9	0
	Freestone dogger	2	0
	Hard black shale	13	0
	Hydraulic limestone	3	4
Estuarine Beds 59 ft. 8 in.	Dry blue shale	8	0
	Top band of ironstone*	5	0
	Hard shale	2	8
	Ironstone	1	0
	Yellow dry shale	4	6
	Blue dry shale	4	6
	Black shale	0	6
	Dry blue shale	6	0
	Black hard shale	0	6
	Alum shale	2	6
	Hard dry shale	6	0
	Dry sandy shale	3	0
	White clay	2	0
	Light coloured clay	2	0
	Fire clay	12	0
The Dogger	Ironstone bed		
		121	8

* This is, probably, the ironstone bed seen just beyond the station, and the one mentioned as associated with the hydraulic limestone. See page 203.

Shaft sunk for Ironstone at Kirkham.

		Ft.	In.
Surface clay and decomposed limestone.	Clay and shale	6	0
Millepore Bed	Oolitic limestone	3	0
Estuarine Beds 15 ft. 0 in.	Grey shale	15	0
	Hydraulic limestone	4	0
Estuarine Beds 86 ft. 0in.	Dark shale	18	0
	Sand	27	0
	Blue shale	23	0
	Clay	18	0
The Dogger	Ironstone	12	0
		126	0

The first of these sections has been variously interpreted by different authors. Dr. Wright,* who was the first to publish an account of it, includes the first five divisions in the Millepore Bed, the next two are grouped as the Dogger, and below this comes the Blue Wick Sands and the Shales of the Upper Lias. Mr. Hudleston,† who again quotes the section, seems also to consider the five feet of ironstone as part of the Blue Wick Sands, and consequently below the Dogger; but he does not state what division he considers to mark the horizon of that bed, although he classes the beds below as Supra Liassic Shales. It seems, however, that if the Dogger is present in this section at all, it must come in below the Hydraulic Limestone, as this latter has been traced throughout the Howardian Hills in a position evidently some little distance above the base of the Oolites. Judging also from the fact that the Dogger is seen on the hillside below at about the 100-feet contour line, whereas the summit of Mount Pleasant shaft is about 235 feet above sea-level, it is probable that this section did not penetrate any of the Lias beds, in fact, barely reached the true Dogger.

The second section renders this more clear, for here the ironstone at the base of the shaft, which is the one that was worked, is evidently the Dogger seen at the mouth of the adit; and it is some considerable distance below the Hydraulic Limestone, which is exposed on the hillside at from 80 to 90 feet above the adit to this mine. The thickness of the different Estuarine Beds in these two sections varies considerably, but the total thickness is nearly the same in both.

The amount of shale mentioned in the first of these sections is curious, and we cannot help thinking that the terms employed by the miners have been interpreted to suit a preconceived idea.

At Acklam these strata, which consist principally of sands or soft sandstone, are reduced to about 50 feet in thickness; while at Kirkby Underdale there is merely a thin band between the Millepore Bed and the Lias, and south of this the whole of the

* Quart. Journ. Geol. Soc., vol. xvi. p. 33, 1860.
† Proc. Geol. Assoc., vol. iii. p. 324, 1874.

Lower Oolites are only just recognizable from the few fragments here and there.

When these beds again come out from beneath the Chalk in South Yorkshire they are, as we have stated, very thin, and appear to have almost lost their estuarine character; in fact it is doubtful whether the whole of the Inferior Oolite in this region may not be marine.

Coal Seams.—Although the principal workable coals occur at from 50 to 100 feet below the Grey Limestone and therefore are in the Middle Estuarine Series, there are also towards the base of this series one or two unimportant coal seams which it will be better to describe here.

These usually occur not far above the Dogger, and may be observed at several points along the cliffs between the Peak and Whitby. In the section of the Lower Estuarine Series at Blea Wyke there are three small seams varying in thickness from 2 to 6 inches. These come in again on the north side of Robin Hoods Bay, and are seen in the cliffs at Hawsker Bottoms, north of which the lowest band appears to die out.

Although none of these seams are now of any importance, nevertheless in former times workable coals appear to have been obtained from them.

Prof. Sedgwick, in his account of the coast, states that coal was worked in 1821 at Brandy Hole north of Robin Hoods Bay and gives the following section:—

4. Thick beds of strong coarse sandstone.
3. Alternations of shale and grit - - - 30 to 40 feet.
2. Ferruginous coarse grit (dogger).
1. Alum shale at base of cliff.

Good coal was extracted from one of the shale beds subordinate to No. 3.*

Young and Bird also mention that in 1826, "an immense mass of the upper part of the cliff between Whitby and Saltwick fell down, and the poor people of Whitby found *some tons of good coal* among the broken strata."†

Inland these thin coal seams were met with in the boring at Ruswarp,‡ where the lowest band has increased to 11 inches, a thickness quite sufficient in old times to have been worth working if it had occurred at only a slight depth beneath the surface.

In the Maybecks boring§ there does not appear to be anything more than mere streaks of coal in the lower part of the Estuarine Series.

In the cliffs near Goldsborough, north of Whitby, several of the shales, as we have mentioned, are good fire-clays, but no coal seams are seen.

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* Annals of Philosophy. 1826. p. 355.
† Geol. Survey of the Yorksh. Coast. 2nd Edition, p. 121.
‡ See page 185.
§ See page 187.

The same is the case in Commondale, where one of these fire-clays is worked.

In Basedale a coal has been worked which is about 70 feet above the Dogger, but this seam must be very local, and apparently dies out in a very short distance.

The following account of shafts and borings which seem to have been sunk in search of this coal, but did not pass through it, show how very uncertain this seam must be:—

Coal Sinkings at Baysdale, 12 *miles from Whitby.**

No. 1.

	Ft.	In.
Sand and gravel	4	4
Brown sandstone	3	0
Metal	3	0
White freestone	4	6
Blue metal	3	0
Blue bind	1	6
Blue metal	3	0
Blue flinty stone	1	5
White freestone	10	6
Blue metal	4	6
White freestone	27	0
Blue metal	1	0
White freestone	4	6
White freestone	16	6
Blue metal	3	0
White freestone	1	0
Blue metal	1	4
White freestone	0	6
Blue metal	1	6
White freestone	11	2
Total	106	3

No. 2.—Sinking.

	Ft.	In.
Walling from the surface	10	6
Drab-coloured stone	19	6
Blue metal	34	6
White freestone	4	4
Blue metal	9	0
White post	1	8
Blue metal	6	0
Here coal was expected.		
White freestone	21	0
Total	106	6

Boring from the bottom of the pit.

	Ft.	In.
White freestone mixed with blue whin	12	0
Rag stone	20	0
Alum shale	15	0
Total	153	6

* Winch, Trans. Geol. Soc., vol. v. p. 551.

No. 3.—Boring.

	Ft.	In.
Peat moss	4	0
Blue clay	6	0
Blue metal	3	0
White freestone	1	6
Blue bind	10	6
Blue metal	1	6
White stone	4	0
Blue stone with coal pipes	6	0
Blue metal with post girdles	6	0
White freestone	4	6
Blue raggy stone	4	6
Dark brown post with water	9	0
Blue metal mixed with ironstone balls	4	0
Total	64	6

Left off at a coarse white post with a large feeder of water.

Near Spires House at the south end of Rosedale and along Hartoft Beck a coal has been worked a short distance above the Dogger, which is probably the lowest seam coming in again for a short distance. Just above these pits is a strong bed of sandstone full of the vertical markings of *Equisetites*.*

In the Howardian Hills a coal has been worked below the Millepore Bed in the little valleys on Yearsley Moor and to the south of Gilling, but it cannot be of any thickness as all the workings are close to the outcrop and there are no pits of any depth. We cannot be certain whether this is a different seam from that at Coxwold, but we fancy it must be, as no mention is made of the Millepore Bed in the Newburgh boring which must have been passed through if these seams are the same, consequently we have included the coal worked at Coxwold with the Middle Estuarine Series to be described presently.

The Eller Beck Bed and Hydraulic Limestone.

The first of the above names is derived from Eller Beck near Goathland, where this bed is well developed. In the Howardian Hills a bed of Hydraulic Limestone comes in just over the ironstone of the Eller Beck Bed or perhaps partly replaces it; this limestone is much more conspicuous and better known than the ironstone beneath, consequently in this region we describe the bed under the second of these two names. Where first seen on the coast the Eller Beck Bed is scarcely to be recognized from the Estuarine sandstones which lie above and below it, the only evidence of it being one or two obscure bands of ironstone with marine shells which are not always very easy to find. In the interior, however, it becomes much thicker and more important; towards the west developing into a thick ironstone which has been worked, while in the south it changes, as we have said, to an hydraulic limestone which is of some economic value.

* Prof. Phillips has remarked that *Equisetaceæ* frequently constitute a great part of the thin coal-beds. Geol. of Yorksh. Coast, 3rd Ed., p. 196.

The Eller Beck Bed is first seen rising from the sea, at a point called Iron Scar, about a mile north of Cloughton Wyke, where the section is as follows:—

	Ft.	In.
Sandstone, close-grained in upper part, and flaggy with streaks of dense ironstone near the base	12	0
Thin band of ironstone with *Nucula*, *Astarte minima*, in great numbers, also *Gervillia acuta*, *Arca* (sp.), *Corbula*, *Tancredia*, and *Littorina*	0	3
Shales well bedded and ferruginous	3	0
Thin band of ironstone, unfossiliferous	0	3
Shales, similar to above	1	6
Ironstone	0	3
Total	17	3

The section remains practically the same over a considerable distance, the bed being easily traced at the top of the undercliff, between the Peak and Hayburn Wyke, up to the great Peak fault. It is not seen in the cliffs again till we reach Hawsker, where it first comes to the face of the cliff immediately to the north of Maw Wyke, from which point it continues to High Whitby, and after turning inland for a short distance once more re-appears just north-west of Saltwick Nab. From this point it continues in the cliff, though it is quite inaccessible, to the mouth of Whitby Harbour, where it is the capping rock of the East Cliff, and is seen close to the Church Stairs. It is here about 100 feet above the Dogger, and consists of thin fissile sandstone with ferruginous shale below, the latter containing ferruginous nodules in which small fossils are found. To the west of Whitby the first clear exposure is in Cat Beck near Kettleness, from which point the outcrop can be followed in either direction for some distance. The section here is:—

	Ft.	In.
Flaggy sandstone	4	0
Shale	7	0
Ironstone with *Gryphæa*, *Astarte minima*, *Nucula*, sp., *Littorina*, at the base	0	6
Shale	1	0
Ironstone (impure)	1	0

Due east of Hinderwell a somewhat similar section is seen in the face of the cliff, the ironstone bands being much thinner. This is the last place where strata so high as the Eller Beck Bed are seen in the cliff. Inland it has been recognised in the little stream close by Lofthouse Station, where a small quarry shows—

	Ft.	In.
Rather hard evenly-bedded sandstone	15	0
Shale with ferruginous nodules at base containing casts of a small *Gryphæa*	2	0
Thick sandstone.		

A similar section is seen in the banks of the next stream to the east, where crossed by the railway.

In an old quarry east of Brotton, and in another just west of the village, the fissile sandstone and shale are seen resting on the

thick sandstone, as above. South-west of this the Eller Beck Bed has a very clear outcrop under Mill Holme, though it presents no features of interest.

In a quarry near the road at Boosbeck there is the following section—

	Ft.	In.
Clay	6	0
Thin sandstone	4	0
White shale	4	0
Ironstone	0	4
Sandstone	20	0

Further south in this district the Eller Beck Bed is not known, neither has it been recognised on the Eston or Upleatham Hills. Along the valley of the Esk it again comes in, being exposed at Lealholm Bridge close to the station, and in Trinket Wood; at both of which places the ironstone is seen, but slightly out of place. It also re-appears at Egton; but, though masses of the fossiliferous ironstone can be found in the beck below the village, there is no clear section.

South of the Esk the Eller Beck Bed forms a very convenient horizon in the thick series of Estuarine Beds. It is probably continuous, for wherever sections occur in the right place there is little difficulty in recognising the bed.

Throughout a great part of this district the rock may be described as a flaggy, fossiliferous sandstone, or sometimes oolitic ironstone, resting on shales in which occur either nodules or thin continuous beds of very fossiliferous ironstone. Both its upper and lower boundary is indefinite, there being a gradual passage into the ordinary estuarine beds.

The most easterly exposure south of the Esk valley is in a little stream that flows into the Little Beck Alum Works. The section here is as follows:—

	Ft.	In.
Sandstone, flaggy and micaceous, splits to very thin laminæ in lower part	5	0
Shales, sandy in upper part, bluish grey below	3	0
Sandstone, carbonaceous, and containing occasional ferruginous nodules composed of shells in the middle	3	0
Ferruginous sandy shale	0	5
Ironstone with *Pholadomya Sæmanni*	0	5
Ferruginous shale	0	7
Ironstone casings with liquid mud inside	0	3
Total	12	8

The ironstone nodules in the middle of the second band of sandstone contain nearly the same fossils as the "*Pholadomya* ironstone" below. The chief are—a small *Gryphæa*, *Astarte minima*, *Cerithium*, *Cardium*, *Avicula*, *Gervillia acuta*, and a few other fossils.

A small distance above Falling Force, near Old May Becks, the hard sandstone at the top of this section may be seen dipping into the stream, but the shales and fossiliferous parts are completely covered by débris.

In Eller Beck, the eastern branch of the Murk Esk, at Walk Mill Force below Darn Holm is the typical section where this bed was first made out by Mr. G. Barrow.* The section here is :—

	Ft.	In.
Sandstone, hard at top, flaggy at base, with a few impressions of *Modiola* and *Avicula*	10	0 to 12
Ferruginous sandy shale	4	0
Hard ironstone crowded with small fossils	0	5
Ferruginous shale	5	0
Ironstone full of comminuted shells	1	2
Shales.		

The lower bed of ironstone is very hard and calcareous, and contains a considerable variety of fossils, of which a list is given at page 205; *Pholadomya Heraulti ?* and *Myacites* in a vertical position being very abundant. This bed, which was first noticed by Bewick,† is locally known as "Julian's line," as it is supposed to have been worked by the Romans.‡

This lower seam has been followed with occasional small gaps over a very large area. It has not, however, been recognised to the north-east of Eller Beck, but re-appears on the south of this preglacial valley at Mollion Spout and may be traced along the face of New Wath Scar, where the flaggy sandstone has cores in the middle composed of grains of sand enveloped completely in oxide of iron, being, in fact, almost an oolitic ironstone. The ironstone bands below are thinner, and only the lower one contains many fossils. This section may be followed as far as the junction of Wheeldale Gill with Wheeldale Beck. In the former stream the sandstone alone is visible for a considerable distance, but above Archy Crag the first seam of fossiliferous ironstone, 8 inches thick, appears, and another is seen a little higher up, which continues for nearly a mile before they finally disappear.

On the west side of the Murk Esk these beds are seen in Grain Beck, where the following section was measured :—

	Ft.	In.
Hard sandstone	4	6
Oolitic ferruginous sandstone, almost an ironstone	2	0
Flaggy sandstone	2	6
Shale	3	0
Ironstone band	0	2
Shale	3	0
Ironstone band	0	6

About a mile further north in Oakley Beck the sandstone is seen, and, as is shown by the "Cinder Hill," at Narrow Stye End, has evidently been tried as an ironstone. North of this the outcrop is not very clear, although its position is tolerably well fixed by the feature formed by the sandstone above.

Passing round by Egton Grange there is a clear section at the head of the dale in Birchwath Gill, where the typical flaggy sandstone is seen with the shale and fossiliferous ironstone seams below. The section here is :—

* See Geol. Mag., Dec. II., vol. iv. p. 552. 1877.

† Geological Treatise on the District of Cleveland, p. 67. 1861.

‡ An analysis of this ironstone is given on page 450.

	Ft.	In.
Flaggy sandstone	10	0
Shale, with two rows of fossiliferous ironstone at the base	4	0
Total	14	0

On the west side of the dale the feature of the sandstone can be followed to the "Pits" at Holey Intake above Arnecliffe Wood where the ironstone in it has in former times been worked. About a mile to the south-west very silicious oolitic ironstone is seen in a small ditch, and the sandstone, which is very fossiliferous, crops out in the road above Gill Beck.

In Winter Gill the Eller Beck Bed attains its greatest known thickness. The following section was measured here:—

	Ft.	In.
Very hard, close-grained sandstone containing fragments of soft jet and other carbonaceous matter	4	0
Ironstone, sandy and impure	1	0
Ironstone, dark brown, oolitic, slightly magnetic; fossils extremely rare	6	0
Calcareous and ferruginous stone, with a few small fossils	2	0
Hard, flaggy, micaceous, white sandstone, passing gradually downwards into a sandy shale	20	0
Sandy marl	1	6
Dense limestone, apparently unfossiliferous	0	4
Argillaceous micaceous shale, much resembling the shales of the Middle Lias	5	0
Ironstone with abundance of the characteristic *Pholadomya* and other fossils*	1	0
Total	40	10

The position of this section can be fixed by the old drifts into the stream banks and by the presence of a heap of the oolitic ironstone in the beck. The ironstone varies much in thickness, reaching 13 feet at the shaft, but changing so fast that it cannot be depended on. It probably soon dies out entirely in each direction. An analysis of the magnetic ore is given on page 451.

On the west side of Glaisdale, close to High Hardhill, there is the following section:—

	Ft.	In.
Flaggy sandstone and shale	15	0
Shale	4	0
Ironstone, fossiliferous†	0	11
Shale	1	0
Total	20	11

A little further north in the "Sandstone Quarry" above Hardhill where the Eller Beck Sandstone has somewhat the character of the oolitic ironstone of Winter Gill there is:—

	Ft.	In.
Sandstone and shale with *Equisetites*	3	0
Flaggy very sandy oolitic ironstone	2	6
Thick sandstone	6	0
Total	11	6

* See List of Fossils, p. 205.

† A quarter of a mile south of High Hardhill this ironstone contains *Astarte minima*, *Gervillia* sp., *Ostrea* sp.

Above Post Gate Hill the Eller Beck Bed has been tried at two places for ironstone. The easterly hole has fallen in, but the westerly one shows shale with three rows of ironstone.

Nearly due north of this at the point where the Whin Dyke crosses Busco Beck at Low Wood the Drift has been cut through and a section immediately south of the Dyke shows:—

	Ft.	In.
Thick sandstone	6	0
Shaly sandstone with soft jet	10	0
Shale and soft grey sandstone	2	6
Ironstone with carbonaceous markings	0	1
Micaceous flaggy chert	1	0
Shale and thin chert	2	8
Two thin irregular ironstones, unfossiliferous	0	4
Shale	3	4
Ironstone full of fossils, *Astarte minima, Trigonia, Ostrea, Myacites, Pholadomya, Pinna*	1	5
Shale, lower part estuarine	4	0
Total	31	4

It is not clear how much of this section belongs to the Eller Beck Bed.

On the south side of the Esk at Crankly Gill the fossiliferous ironstone is again seen, but is very silicious.

In Fryup, the only place, where the Eller Beck Bed has been recognised, is at the head of Great Fryup, where the fossiliferous sandstone forms a low cliff for about a mile. The fossiliferous ironstone, however, cannot be traced here.

Near Danby Dale and Westerdale, this marine bed being high up on the moors, there is a scarcity of sections. There is a small exposure between these dales at Stone Ruck Hill, and another in the Sandstone Quarry, a quarter of a mile further south, where we find:—

	Feet.
Flaggy sandstone, full of fossils and wood, and with traces of oolitic ironstone: *Pecten, Ostrea, Trigonia, Astarte minima*, &c.	13

The fossiliferous beds are also found at two or three points on the moors round Westerdale, so that it is probable they are continuous over the whole district, though not always recognised.

In the neighbourhood of Basedale, although there are no sections of the Eller Beck Bed, it can easily be traced round the sides of that dale and across the moors to the Ingleby escarpment, when the outcrop divides into two branches, one turning north above Park Plantation, the other south under Burton Howe to the Incline Top. The incline here was originally made to work the ironstone in this bed, and it is evident that it must have been somewhat thicker at the outcrop to have warranted such an outlay. The section here is:—

	Ft.	In.
Soft sandstone with very large vertical *Equisetites* and soft jet	10	0
Reddish-brown shale, coaly at base	10	0
Thin, hard, flaggy sandstone	3	0
Finely laminated shale	2	0
Ironstone with fossils	0	9

Continuing along the escarpment, where the outcrop is fairly clear, there is a fine section in Blue Bell Trough, showing:—

	Ft.	In.
Estuarine sandstones and shales	50	0
Thin, flaggy sandstone	3	0
Shales, bluish and well bedded	6	0
Ironstone with minute fossils	2	0
Shale - 1 ft. 0 in.; Ironstone - 0 „ 4 „	1	4
Shale - 1 „ 6 „; Ironstone - 0 „ 6 „	2	0

Passing round into Bilsdale, the Eller Beck Bed gradually becomes thinner and untraceable for some distance down the dale, but opposite Chop Gate a small band of ironstone crosses the road above William Beck; this is, however, quite an isolated outcrop. In Fangdale Beck this band of ironstone is 2 feet thick, with the typical flaggy sandstone and shaly sandstone with soft jet above. North of this point the outcrop is clear for some distance, but it is soon lost to the south. On the opposite side of the dale the ironstone is exposed in the roads above Low Crosset, and can be traced some distance to the south.

In Bonfield Gill, close by the road into Bransdale, fossiliferous flaggy sandstone is seen, and further up the shale with a foot of ironstone: the position of the bed can be clearly followed on both sides of the dale till it enters the stream again some distance above the last intake.

There are no sections of the Eller Beck Bed in Bransdale or Farndale, but a marked feature and occasional fragments of fossiliferous grit allow the bed to be traced nearly continuously.

Rosedale shows several good sections. The first in the "Crag" south-west of Rosedale Abbey being:—

	Ft.	In.
Sandstone	20	0
Shale	7	0
Fossiliferous Ironstone dogger	0	6
Shale	1	0
Ferruginous fossiliferous grit	2	0
Estuarine shale and thin sandstones	30	0
Total	60	6

The other exposures are in Northdale, where the Eller Beck Bed forms a bold scar above the stream. A section near Coal Pit Hill shows:—

	Ft.	In.
Estuarine shale and thin sandstone.		
Flaggy sandstone with plants and *Avicula*	3	0
Shale	3	0
Ironstone, fossiliferous with *Myacites*, *Astarte*, *Pholadomya*, *Ostrea*, *Gervillia*	0	6
Shale.		
Total	6	6

In North Gill it has altered to :—

	Ft.	In.
Sandstone, flaggy at base and full of fossils - - -	17	0
Shale with line of tough nodules - - - -	6	0
Ironstone with *Pholadomya lyrata* or *P. Heraulti* - -	0	6
Estuarine shale - - - - - - -	11	0
Shale and shaly sandstone.		
Total - -	34	6

The Eller Beck Bed also crops out in the upper part of Hartoft Beck below Low Hamer; and may be followed down the valley as far as Wash Beck House; it here contains *Gervillia acuta*, *Astarte minima*, *Cardium semiglabrum*, *Trigonia*, *Turritella*, and other small fossils.

Along the northern part of the moors to the west of Bilsdale as the Eller Beck Bed is rather thin it is not easily found, unless the strata are cut through by stream sections, or when this bed occurs close under the bearing rock of a scar, as often happens in the great escarpment, where it has usually a thick ferruginous sandstone above.

In the long outlier of Cold Moor this brown sandstone is well seen, but there are no sections below, so that it was impossible to find the marine bed. On the roughly triangular area of Dromonby Hill the brown sandstone caps the scar, in the face of which the fossiliferous ironstone is seen, being from a few inches to a foot in thickness; the depth to the Dogger below being about 100 feet.

At the north end of Carlton Bank it is not seen, probably owing to the accumulation of *débris* from the brown sandstone, but passing south-east, a section is exposed in the road leading off the moor to Staindale Farm, which is as follows :—

	Ft.	In.
Carbonaceous shale - - - - - -	0	9
Flaggy sandstone - - - - - -	6	0
Shale - - - - - - -	0	6
Ironstone with fossils - - - - - -	0	6

From this point it can only be followed for a short distance.

On the south side of Raisdale and on Bilsdale West Moor [illegible] outcrop is fairly clear, fossiliferous ironstone fragments [illegible] in the Bridle Road leading down to Chop Gate and [illegible] south in the scar called "The Clough" overlooking [illegible]

The small section of shale with little ironstone [illegible] the sandstone quarry at the extreme north-west [illegible] escarpment probably represents the Eller Beck [illegible] mention of it is made in the boring, put down [illegible] to the south.*

South of Osmotherley for a considerable [illegible] evidence of the Eller Beck [illegible]

flags seen close by Hunter's Hill in the hollow north-east of Nether Silton.

On Snilesworth Moor there are some very interesting inliers of the Eller Beck Bed. The first of these is in the uppermost reaches of the Rye, near Skelbeast Crag, a little below the coal workings on Coal Ridge. At the point where the stream divides a fine-grained flaggy sandstone may be seen having a few casts of fossils near the base; this is succeeded by shale and though not seen the thin ironstone seam is probably at the base of this. Following the outcrop round into Proddale Beck, the ironstone is 2 feet thick, and contains a considerable number of fossils; further down on the east side of the stream there is no evidence of the exact outcrop, but on the west side of the Rye its position may be fairly well made out by the flaggy sandstone which makes a small but continuous feature. Passing up for a short distance into Wheat Beck, the ironstone is seen again in the stream, being 1 foot 6 inches thick, and on the south bank may be followed till it sinks beneath the Rye at Burnt House, where the ironstone is somewhat thinner.

Along the south-east side of Arns Gill the fragments of ironstone seen at intervals mark the position of the Eller Beck Bed for a considerable distance up the dale, and drifts have been made into it.

Nearly a mile east of this, in Blow Gill, is another inlier of the Eller Beck Bed. It consists of thin flaggy sandstone, with about 8 feet of shale below. Beneath the shale is a seam of light coloured, somewhat oolitic ironstone, containing a great number of fossils, of which *Pholadomya Heraulti* (*Ph. Murchisoni*, Ag.) is by far the most abundant. The section is :—

	Ft.	In.
Flaggy sandstone.		
Shale - - - - - - - - -	8	0
Ironstone very fossiliferous - - - - - -	2	6

Near the lower end of the stream a third inlier of this bed is exposed, and just below Blow Gill Farm the following section was measured :—

	Ft.	In.
Sandstone.		
Shale - - - - - - - - -	5	0
Thin ironstone - - - - - - -	0	4
Shale - - - - - - - - -	3	0
Ironstone with fossils - - - - - -	0	6
Shale.		

There appears to be four or more thin ironstone seams here but they are not all exposed in one section.

At Coneygarth Hill on the outlier north-west of Kirkby Knowle this seam of ironstone is sufficiently thick to make a marked feature and strew the hillside with its fragments, but as soon as the hill becomes steeper and the Oolite sandstones have a narrower outcrop this bed is again lost sight of.

A flaggy sandstone containing fossils, which is seen in two places in the main escarpment opposite this hill, is probably the upper part of the Eller Beck Bed, but from this point there is no evidence till Skipton Hill near Thirlby is reached.

Here the bed has considerably altered in character, and a thin limestone sets in, which gradually becomes thicker and more important towards the south, while the ironstone which accompanies it is less noticeable. This bed which we now describe under the name of the Hydraulic Limestone is a hard grey argillaceous limestone never more than a few feet in thickness, but which, from the fragments of it weathering to a whitish colour, is very conspicuous when it comes to the surface. This rock first becomes noticeable below Whitestone Cliff where it forms an outlier round Skipton Hill and may be followed along the escarpment below Gormire Lake. To the west and south of Hood Hill the bed is exposed at several places, having apparently been worked below Penfitt Wood; east of this it is seen at Acre House and between High Kilburn and Kilburn Thicket, but the outcrop in this direction is rather obscure.

Throughout the Howardian Hills the Hydraulic Limestone is a more important bed; and from its peculiar lithological character forms a very conspicuous outcrop, which is of great assistance in unravelling the intricate structure of this region.

Over a portion of the district there are two beds of this limestone separated from each other by a few feet of shale. The upper of these beds, which is only two feet thick at Maidensworth, is not always present, and its outcrop is too obscure to be traced on the map; it is therefore with the lower bed that we are principally concerned.

This bed of limestone, which is the one shown on the geological map, has a thickness of about four feet; it is a hard close-grained argillaceous limestone with a conchoidal fracture, and contains a few fossils, which, however, usually break transversely, and are therefore difficult of extraction and determination. A freshly broken surface of the stone is of a light greyish blue colour, but on exposure to the air it becomes white. It has been burnt for lime at several places in the neighbourhood of Terrington, and is said to make very good lime for agricultural purposes; it is also frequently used as a roadstone. Below the limestone is a bed of ironstone very full of fossils, of which the principal are *Unicardium globosum* ?, *Ostrea gregaria* ?, *Myacites*, *Rhynchonella*.

In the Coxwold area the Hydraulic Limestone crops out at Angram Grange, close to the southern fault, fragments of the rock being seen in the beck below the house. South of Garbut Gill it has been worked, but the outcrop at the western end of these hills is usually not very clear although fragments of the rock are seen at a few places.

In most of the numerous valleys west and south of Gilling Park the limestone is well seen, particularly in Newburgh Park and on Yearsley Moor. There are also good exposures below Grimston Moor, Scackleton, Howthorpe, and along the southern

escarpment to the neighbourhood of Terrington, where it is interrupted by a fault for a short distance, but crops out again in the side of the bank west and south of Ganthorpe. A well at Moorhouses near Terrington is said to have gone through both beds of this limestone.

The outcrop is fairly well marked on the hill above Mowthorpe by a slight feature which it makes, and by the clayey nature of the ground, covered by the peculiar white fragments of the rock, which render it very conspicuous.

The Hydraulic Limestone forms a large outlier on the hill at Stittenham, but about Bulmer it is much broken up by the faulted character of the ground. Between this and Whitwell, however, it spreads out, and forms the largest outcrop that this little bed makes anywhere in the county. It is well seen at several places on the sides of the Derwent valley,* and, skirting along the hill-edge above the Abbey, is cut off by the large fault near Spy Hill. The rock appears again on the hill to the south of Gally Gap and about Burythorpe; but south of this it cannot be traced as a distinct bed, although traces of the rock are seen near Leavening and at Garrowby.

In South Yorkshire the Hydraulic Limestone again appears at Sancton, where it is seen in a field at the side of the road just south of the village, and appears to have been worked at some time.

Between here and Newbald Sike the beds are overlapped by the Chalk, which comes down on the Lias; and although they crop out again along the bank there is no evidence of them as far as Newbald. South of this village the outcrop of the Hydraulic Limestone and the clay above become much clearer, and fragments of the limestone are frequently seen strewn over the fields.

At the side of the road going up the hill east of Hotham, and a little above the Middle Lias section previously mentioned, the limestone, which is three feet thick, has been quarried for mending the roads, and is better exposed than anywhere else in the district. The outcrop still continues clear for some distance to the south, and both the clay and fragments of limestone are seen in the railway and road east of Everthorpe, and about South Cave.

In the stream at Ellerker, as given in the section above,† the limestone is 2 ft. 6 in. thick, with 6 ft. of shale below, and then the sandstone at the base, but the beds above are not very clear; it is evident, however, that there is scarcely any thickness of measures, as the Cave Limestone crops out almost immediately above at the windmill, and the trial-holes also show that there is not much difference in the beds.

South of this the clays between the two limestones thin out, and the Hydraulic Limestone cannot be traced as a separate bed.

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* *See* sections on pages 190, 191.

† Page 176.

Fossils from the Eller Beck Bed and the Hydraulic Limestone.

FOSSILS.	LOCALITIES.
CRUSTACEA.	
Estheria concentrica ?, *Bean*. - -	Cloughton.
BRACHIOPODA.	
Rhynchonella, sp. - - -	Howardian Hills.
LAMELLIBRANCHIATA.	
Avicula, sp. - - - -	Little Beck; Eller Beck; Hartoft Beck.
Exogyra, sp. - - - -	Eller Beck.
Gervillia acuta, *Sow*. - - -	Hayburn Wyke; Little Beck; Eller Beck; Hartoft Beck.
—— lata, *Phil*. - - - -	Eller Beck ?
—— prælonga, *Lyc*. - - -	Eller Beck.
—— tortuosa, *Sow*. - - -	Howardian Hills.
—— sp. - - - -	Wintergill.
Gryphæa, sp. - - - -	Little Beck; Kettleness.
Ostrea gregaria ?, *Sow*. - - -	Howardian Hills.
—— sp. - - - -	Wintergill; Eskdale.
Pecten lens, *Sow*. - - -	Murk Esk; Grain Beck; Julian Park.
—— sp.	
Pinna cuneata, *Phil*. - - -	Eller Beck.
Arca, sp. - - - -	Hayburn Wyke; Hartoft Beck.
Astarte minima, *Phil*. - - -	Common nearly everywhere.
—— sp. - - - -	Hartoft Beck.
Cardium lingulatum, *Lyc*. - -	Eller Beck.
—— semiglabrum, *Phil*. - -	Hartoft Beck.
—— striatulum, *Sow*. - - -	Howardian Hills.
—— sp. - - - -	Eller Beck.
Corbis elliptica ?, *Lyc*. - - -	Eller Beck.
Corbula involuta, *Münst*. - -	Eller Beck.
—— sp. - - - -	Hayburn Wyke; Hartoft Beck.
Cucullæa, sp. - - - -	Eller Beck.
Cypricardia, sp. - - -	Eller Beck.
Cyprina, sp. - - - -	Eller Beck.
Leda lachryma, *Sow*. - - -	Eller Beck.
—— sp. - - - -	Hartoft Beck.
Myacites decurtatus, *Phil*. - -	Eller Beck.
—— modicus, (*Bean*) *Lyc*. - -	Wintergill.
Nucula, sp. - - - -	Kettleness; Hayburn Wyke.
Pholadomya acuticosta, *Sow*. - -	Eller Beck.
—— lyrata, *Sow*. or Ph. Heraulti, *Ag*. -	Eller Beck; Murk Esk; Snilesworth.
—— Sæmanni, *L. & M*. - -	Little Beck.
Tancredia axiniformis, *Phil*. - -	Eller Beck.
—— sp. - - - -	Hayburn Wyke.
Trigonia spinulosa, *Y. & B*. (T. striata, *Phil*.)	Eller Beck.
—— sp. - - - -	Eller Beck; Hartoft Beck.
Unicardium globosum ?, *Ag*. - -	Howardian Hills.
—— sp. - - - -	Eller Beck.
GASTEROPODA.	
Kilvertia, sp. - - - -	Wintergill.
Littorina, sp. - - - -	Eller Beck; Hayburn Wyke; Kettleness.
Phasianella, sp. - - -	Eller Beck.
Turritella quadrivittata ?, *Phil*. -	Eller Beck.
—— sp. - - - -	Hartoft Beck.

CHAPTER VII.

THE LOWER OOLITES—*continued.*

MILLEPORE SERIES.

THESE beds have received their name from the little Polyzoan *Entalophora* (*Spiropora*, *Cricopora*, or *Millepora*) *straminea*, Phil., the fragments of which in some places occur in great numbers on the surface of the rock. The name appears to have been first published by Wright in 1860, although it was in common use before that time.

*Synonyms and Foreign Equivalents** :—"Ironstone and Sandstone" (part), Young and Bird, Geol. Survey of the Yorkshire Coast, p. 90, 1822,† and p. 94, 1828; "Pier Stone" (part), Murchison, Geol. Trans., 2nd. ser., vol. ii., p. 297, note, 1829:‡ "Impure Limestone or Oolite" (part) [considered then to be the equivalent of the Lincolnshire and Cave Oolite, and the Bath Oolite], and "Inferior Oolite of Gristhorpe," Phillips, Geol. of Yorksh., pp. 33, 79, 149, 1829; pp. 3, 51, 121, 1835; "Great or Bath Oolite" (part), Williamson, Trans. Geol. Soc., ser. 2, vol. v., p. 231, 1837; "Brauner Jura γ," Quenstedt, Flözgeb., p. 538, 1843; "Subzone of *Ammonites Sauzei*, ? Zone of *Ammonites humphriesianus*" (part), Oppel, Juraformation, p. 333, 1856; "Fimbria-stage of the Inferior Oolite," Lycett, Cotteswold Hills Handbook, p. 34, 1857; "Zone of *Ammonites Murchisonæ*," (part), Wright, Monogr. Brit. Ool. Echinoderms, pp. 418–433, 1856; "Inferior Oolite Limestone (part), Millepore Bed," Wright, Quart. Journ. Geol. Soc., vol. xvi., pp. 17, 31, 1860;§ "Zone of *Ammonites Sowerbyi*," Waagen, Der Jura in Franken, 1864, and Benecke, Geog. Beitrag, I. p. 507, 1867; Judd, Geol. of Rutland (Geol. Survey), pp. 8, 39, 1875; "Inferior Oolite (part), Millepore Oolite," Phillips, Geol. of Yorksh., p. 35, 1875; "Millepore Series," Expl. 95, S.W. (Geol. Survey), p. 3, 1880.

The lithological character of this series presents two very different phases where exposed on the east and south-west sides of the Yorkshire basin respectively. On the coast these beds are best known under the name "Millepore Series," but in the Howardian Hills and South Yorkshire they have been generally

* The Millepore Bed is probably also contemporaneous with a part of many of the foreign equivalents given for the Grey Limestone on page 228.

† There was considerable confusion at this early date as to the relative position of the Millepore Bed and the Grey Limestone; the former being considered to occupy a higher position than the latter. Both W. Smith and Young and Bird mistook the Oolite of Whitwell (Millepore Series of the Howardian Hills) for the Coral Rag.

‡ This name, which was adopted from the pier at Scarborough being partially built of this rock, appears to have been in general use by W. Smith and others before this time, but this is the earliest publication of it we have been able to discover, although the author is describing another district. The name was used for both the Millepore Bed and the Grey Limestone, which were not distinguished at that time, but considered "according to Mr. Smith the equivalent of the great oolite."

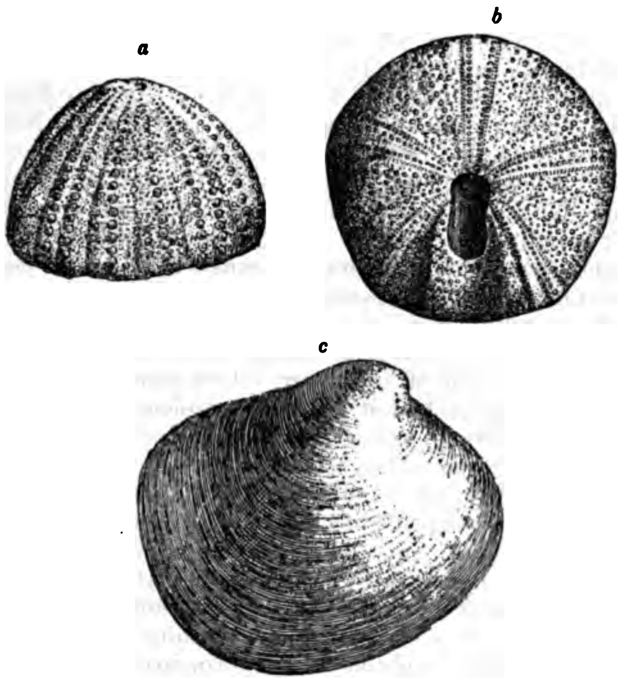
§ In this description of the zones of the Inferior Oolite, Dr. Wright does not make it very clear whether he refers the Millepore Bed to the zone of *Am. Murchisonæ* or *Am. humphriesianus.*

called the "Whitwell or Cave Oolite." As they disappear towards the north it is mainly on palæontological grounds that the two can be correlated.

On the coast this rock is not a true limestone, but has more the nature of a very hard and siliceous calcareous sandstone with ferruginous partings, in fact the exposed situations which it occupies on the shore, and the manner in which it forms as it were a breakwater to the softer strata behind, testifies to its extremely hard nature. It is a false-bedded partly oolitic rock, full of the remains of Polyzoa, Echinodermata, &c., in a fragmentary condition, and has every aspect of having been formed in comparatively shallow water.

FIG. 11.

Fossils from the Millepore Bed.



a, Stomechinus germinans, *Phil.* (after Wright) $\frac{2}{3}$; *b*, Pygaster semisulcatus, *Phil.* (after Wright) $\frac{1}{2}$; *c*, Ceromya bajociana, *d'Orb.* (after Lycett and Morris).

Resting on this hard rock at Yons Nab are a series of marly shales with a few ferruginous bands and some sandstone, which, on account of the fossils that they contain, must be included in this group; they are nevertheless very different from the main mass of the Millepore Series. This upper portion is very local, and has been only observed on the south side of Cayton Bay, where the following section was measured :—

Continuing along the escarpment, where the outcrop is fairly clear, there is a fine section in Blue Bell Trough, showing:—

	Ft.	In.
Estuarine sandstones and shales	50	0
Thin, flaggy sandstone	3	0
Shales, bluish and well bedded	6	0
IRONSTONE with minute fossils	2	0
Shale - 1 ft. 0 in.; IRONSTONE - 0 „ 4 „	1	4
Shale - 1 „ 6 „; IRONSTONE - 0 „ 6 „	2	0

Passing round into Bilsdale, the Eller Beck Bed gradually becomes thinner and untraceable for some distance down the dale, but opposite Chop Gate a small band of ironstone crosses the road above William Beck; this is, however, quite an isolated outcrop. In Fangdale Beck this band of ironstone is 2 feet thick, with the typical flaggy sandstone and shaly sandstone with soft jet above. North of this point the outcrop is clear for some distance, but it is soon lost to the south. On the opposite side of the dale the ironstone is exposed in the roads above Low Crosset, and can be traced some distance to the south.

In Bonfield Gill, close by the road into Bransdale, fossiliferous flaggy sandstone is seen, and further up the shale with a foot of ironstone: the position of the bed can be clearly followed on both sides of the dale till it enters the stream again some distance above the last intake.

There are no sections of the Eller Beck Bed in Bransdale or Farndale, but a marked feature and occasional fragments of fossiliferous grit allow the bed to be traced nearly continuously.

Rosedale shows several good sections. The first in the "Crag" south-west of Rosedale Abbey being:—

	Ft.	In.
Sandstone	20	0
Shale	7	0
Fossiliferous IRONSTONE dogger	0	6
Shale	1	0
Ferruginous fossiliferous grit	2	0
Estuarine shale and thin sandstones	30	0
Total	60	6

The other exposures are in Northdale, where the Eller Beck Bed forms a bold scar above the stream. A section near Coal Pit Hill shows:—

	Ft.	In.
Estuarine shale and thin sandstone.		
Flaggy sandstone with plants and *Avicula*	3	0
Shale	3	0
IRONSTONE, fossiliferous with *Myacites*, *Astarte*, *Pholadomya*, *Ostrea*, *Gervillia*	0	6
Shale.		
Total	6	6

In North Gill it has altered to :—

	Ft.	In.
Sandstone, flaggy at base and full of fossils - - -	17	0
Shale with line of tough nodules - - - -	6	0
Ironstone with *Pholadomya lyrata* or *P. Heraulti* - -	0	6
Estuarine shale - - - - - - -	11	0
Shale and shaly sandstone.		
Total - -	34	6

The Eller Beck Bed also crops out in the upper part of Hartoft Beck below Low Hamer; and may be followed down the valley as far as Wash Beck House; it here contains *Gervillia acuta, Astarte minima, Cardium semiglabrum, Trigonia, Turritella,* and other small fossils.

Along the northern part of the moors to the west of Bilsdale as the Eller Beck Bed is rather thin it is not easily found, unless the strata are cut through by stream sections, or when this bed occurs close under the bearing rock of a scar, as often happens in the great escarpment, where it has usually a thick ferruginous sandstone above.

In the long outlier of Cold Moor this brown sandstone is well seen, but there are no sections below, so that it was impossible to find the marine bed. On the roughly triangular area of Dromonby Hill the brown sandstone caps the scar, in the face of which the fossiliferous ironstone is seen, being from a few inches to a foot in thickness; the depth to the Dogger below being about 100 feet.

At the north end of Carlton Bank it is not seen, probably owing to the accumulation of *débris* from the brown sandstone, but passing south-east, a section is exposed in the road leading off the moor to Staindale Farm, which is as follows :—

	Ft.	In.
Carbonaceous shale - - - - - - -	0	9
Flaggy sandstone - - - - - -	6	0
Shale - - - - - - - -	0	6
Ironstone with fossils - - - - - -	0	6

From this point it can only be followed for a short distance.

On the south side of Raisdale and on Bilsdale West Moor the outcrop is fairly clear, fossiliferous ironstone fragments being seen in the Bridle Road leading down to Chop Gate and again further south in the scar called "The Clough" overlooking Bilsdale.

The small section of shale with little ironstone nodules above the sandstone quarry at the extreme north-west point of the main escarpment probably represents the Eller Beck Bed, but no mention of it is made in the boring, put down some little distance to the south.*

South of Osmotherley for a considerable distance the only evidence of the Eller Beck Bed is some fine-grained fossiliferous

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* See page 189.

flags seen close by Hunter's Hill in the hollow north-east of Nether Silton.

On Snilesworth Moor there are some very interesting inliers of the Eller Beck Bed. The first of these is in the uppermost reaches of the Rye, near Skelbeast Crag, a little below the coal workings on Coal Ridge. At the point where the stream divides a fine-grained flaggy sandstone may be seen having a few casts of fossils near the base; this is succeeded by shale and though not seen the thin ironstone seam is probably at the base of this. Following the outcrop round into Proddale Beck, the ironstone is 2 feet thick, and contains a considerable number of fossils; further down on the east side of the stream there is no evidence of the exact outcrop, but on the west side of the Rye its position may be fairly well made out by the flaggy sandstone which makes a small but continuous feature. Passing up for a short distance into Wheat Beck, the ironstone is seen again in the stream, being 1 foot 6 inches thick, and on the south bank may be followed till it sinks beneath the Rye at Burnt House, where the ironstone is somewhat thinner.

Along the south-east side of Arns Gill the fragments of ironstone seen at intervals mark the position of the Eller Beck Bed for a considerable distance up the dale, and drifts have been made into it.

Nearly a mile east of this, in Blow Gill, is another inlier of the Eller Beck Bed. It consists of thin flaggy sandstone, with about 8 feet of shale below. Beneath the shale is a seam of light coloured, somewhat oolitic ironstone, containing a great number of fossils, of which *Pholadomya Heraulti* (*Ph. Murchisoni*, Ag.) is by far the most abundant. The section is:—

	Ft.	In.
Flaggy sandstone.		
Shale - - - - - - - -	8	0
Ironstone very fossiliferous - - - - -	2	6

Near the lower end of the stream a third inlier of this bed is exposed, and just below Blow Gill Farm the following section was measured:—

	Ft.	In.
Sandstone.		
Shale - - - - - - - -	5	0
Thin ironstone - - - - - -	0	4
Shale - - - - - - - -	3	0
Ironstone with fossils - - - - - -	0	6
Shale.		

There appears to be four or more thin ironstone seams here but they are not all exposed in one section.

At Coneygarth Hill on the outlier north-west of Kirkby Knowle this seam of ironstone is sufficiently thick to make a marked feature and strew the hillside with its fragments, but as soon as the hill becomes steeper and the Oolite sandstones have a narrower outcrop this bed is again lost sight of.

A flaggy sandstone containing fossils, which is seen in two places in the main escarpment opposite this hill, is probably the upper part of the Eller Beck Bed, but from this point there is no evidence till Skipton Hill near Thirlby is reached.

Here the bed has considerably altered in character, and a thin limestone sets in, which gradually becomes thicker and more important towards the south, while the ironstone which accompanies it is less noticeable. This bed which we now describe under the name of the Hydraulic Limestone is a hard grey argillaceous limestone never more than a few feet in thickness, but which, from the fragments of it weathering to a whitish colour, is very conspicuous when it comes to the surface. This rock first becomes noticeable below Whitestone Cliff where it forms an outlier round Skipton Hill and may be followed along the escarpment below Gormire Lake. To the west and south of Hood Hill the bed is exposed at several places, having apparently been worked below Penfitt Wood; east of this it is seen at Acre House and between High Kilburn and Kilburn Thicket, but the outcrop in this direction is rather obscure.

Throughout the Howardian Hills the Hydraulic Limestone is a more important bed; and from its peculiar lithological character forms a very conspicuous outcrop, which is of great assistance in unravelling the intricate structure of this region.

Over a portion of the district there are two beds of this limestone separated from each other by a few feet of shale. The upper of these beds, which is only two feet thick at Maidensworth, is not always present, and its outcrop is too obscure to be traced on the map; it is therefore with the lower bed that we are principally concerned.

This bed of limestone, which is the one shown on the geological map, has a thickness of about four feet; it is a hard close-grained argillaceous limestone with a conchoidal fracture, and contains a few fossils, which, however, usually break transversely, and are therefore difficult of extraction and determination. A freshly broken surface of the stone is of a light greyish blue colour, but on exposure to the air it becomes white. It has been burnt for lime at several places in the neighbourhood of Terrington, and is said to make very good lime for agricultural purposes; it is also frequently used as a roadstone. Below the limestone is a bed of ironstone very full of fossils, of which the principal are *Unicardium globosum*?, *Ostrea gregaria*?, *Myacites*, *Rhynchonella*.

In the Coxwold area the Hydraulic Limestone crops out at Angram Grange, close to the southern fault, fragments of the rock being seen in the beck below the house. South of Garbut Gill it has been worked, but the outcrop at the western end of these hills is usually not very clear although fragments of the rock are seen at a few places.

In most of the numerous valleys west and south of Gilling Park the limestone is well seen, particularly in Newburgh Park and on Yearsley Moor. There are also good exposures below Grimston Moor, Scackleton, Howthorpe, and along the southern

escarpment to the neighbourhood of Terrington, where it is interrupted by a fault for a short distance, but crops out again in the side of the bank west and south of Ganthorpe. A well at Moorhouses near Terrington is said to have gone through both beds of this limestone.

The outcrop is fairly well marked on the hill above Mowthorpe by a slight feature which it makes, and by the clayey nature of the ground, covered by the peculiar white fragments of the rock, which render it very conspicuous.

The Hydraulic Limestone forms a large outlier on the hill at Stittenham, but about Bulmer it is much broken up by the faulted character of the ground. Between this and Whitwell, however, it spreads out, and forms the largest outcrop that this little bed makes anywhere in the county. It is well seen at several places on the sides of the Derwent valley,* and, skirting along the hill-edge above the Abbey, is cut off by the large fault near Spy Hill. The rock appears again on the hill to the south of Gally Gap and about Burythorpe; but south of this it cannot be traced as a distinct bed, although traces of the rock are seen near Leavening and at Garrowby.

In South Yorkshire the Hydraulic Limestone again appears at Sancton, where it is seen in a field at the side of the road just south of the village, and appears to have been worked at some time.

Between here and Newbald Sike the beds are overlapped by the Chalk, which comes down on the Lias; and although they crop out again along the bank there is no evidence of them as far as Newbald. South of this village the outcrop of the Hydraulic Limestone and the clay above become much clearer, and fragments of the limestone are frequently seen strewn over the fields.

At the side of the road going up the hill east of Hotham, and a little above the Middle Lias section previously mentioned, the limestone, which is three feet thick, has been quarried for mending the roads, and is better exposed than anywhere else in the district. The outcrop still continues clear for some distance to the south, and both the clay and fragments of limestone are seen in the railway and road east of Everthorpe, and about South Cave.

In the stream at Ellerker, as given in the section above,† the limestone is 2 ft. 6 in. thick, with 6 ft. of shale below, and then the sandstone at the base, but the beds above are not very clear; it is evident, however, that there is scarcely any thickness of measures, as the Cave Limestone crops out almost immediately above at the windmill, and the trial-holes also show that there is not much difference in the beds.

South of this the clays between the two limestones thin out, and the Hydraulic Limestone cannot be traced as a separate bed.

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* *See* sections on pages 190, 191.

† Page 176.

Fossils from the Eller Beck Bed and the Hydraulic Limestone.

FOSSILS.	LOCALITIES.
CRUSTACEA.	
Estheria concentrica ?, *Bean*. - -	Cloughton.
BRACHIOPODA.	
Rhynchonella, sp. - - -	Howardian Hills.
LAMELLIBRANCHIATA.	
Avicula, sp. - - - -	Little Beck; Eller Beck; Hartoft Beck.
Exogyra, sp. - - - -	Eller Beck.
Gervillia acuta, *Sow*. - - -	Hayburn Wyke; Little Beck; Eller Beck; Hartoft Beck.
—— lata, *Phil*. - - - -	Eller Beck ?
—— prælonga, *Lyc*. - - -	Eller Beck.
—— tortuosa, *Sow*. - - -	Howardian Hills.
—— sp. - - - -	Wintergill.
Gryphæa, sp. - - - -	Little Beck; Kettleness.
Ostrea gregaria ?, *Sow*. - - -	Howardian Hills.
—— sp. - - - -	Wintergill; Eskdale.
Pecten lens, *Sow*. - - -	Murk Esk; Grain Beck; Julian Park.
—— sp.	
Pinna cuneata, *Phil*. - - -	Eller Beck.
Arca, sp. - - - -	Hayburn Wyke; Hartoft Beck.
Astarte minima, *Phil*. - - -	Common nearly everywhere.
—— sp. - - - -	Hartoft Beck.
Cardium lingulatum, *Lyc*. - -	Eller Beck.
—— semiglabrum, *Phil*. - -	Hartoft Beck.
—— striatulum, *Sow*. - - -	Howardian Hills.
—— sp. - - - -	Eller Beck.
Corbis elliptica ?, *Lyc*. - - -	Eller Beck.
Corbula involuta, *Münst*. - -	Eller Beck.
—— sp. - - - -	Hayburn Wyke; Hartoft Beck.
Cucullæa, sp. - - - -	Eller Beck.
Cypricardia, sp. - - -	Eller Beck.
Cyprina, sp. - - - -	Eller Beck.
Leda lachryma, *Sow*. - - -	Eller Beck.
—— sp. - - - -	Hartoft Beck.
Myacites decurtatus, *Phil*. - -	Eller Beck.
—— modicus, (*Bean*) *Lyc*. - -	Wintergill.
Nucula, sp. - - - -	Kettleness; Hayburn Wyke.
Pholadomya acuticosta, *Sow*. - -	Eller Beck.
—— lyrata, *Sow*. or Ph. Heraulti, *Ag*. -	Eller Beck; Murk Esk; Snilesworth.
—— Sæmanni, *L. & M*. - -	Little Beck.
Tancredia axiniformis, *Phil*. - -	Eller Beck.
—— sp. - - - - -	Hayburn Wyke.
Trigonia spinulosa, *Y. & B*. (T. striata, *Phil*.)	Eller Beck.
—— sp. - - - -	Eller Beck; Hartoft Beck.
Unicardium globosum ?, *Ag*. - -	Howardian Hills.
—— sp. - - - -	Eller Beck.
GASTEROPODA.	
Kilvertia, sp. - - - -	Wintergill.
Littorina, sp. - - - -	Eller Beck; Hayburn Wyke; Kettleness.
Phasianella, sp. - , - -	Eller Beck.
Turritella quadrivittata ?, *Phil*. -	Eller Beck.
—— sp. - - - -	Hartoft Beck.

CHAPTER VII.

THE LOWER OOLITES—*continued.*

MILLEPORE SERIES.

THESE beds have received their name from the little Polyzoan *Entalophora* (*Spiropora, Cricopora,* or *Millepora*) *straminea*, Phil., the fragments of which in some places occur in great numbers on the surface of the rock. The name appears to have been first published by Wright in 1860, although it was in common use before that time.

*Synonyms and Foreign Equivalents**:—"Ironstone and Sandstone" (part), Young and Bird, Geol. Survey of the Yorkshire Coast, p. 90, 1822,† and p. 94, 1828; "Pier Stone" (part), Murchison, Geol. Trans., 2nd. ser., vol. ii., p. 297, note, 1829:‡ "Impure Limestone or Oolite" (part) [considered then to be the equivalent of the Lincolnshire and Cave Oolite, and the Bath Oolite], and "Inferior Oolite of Gristhorpe," Phillips, Geol. of Yorksh., pp. 33, 79, 149, 1829; pp. 3, 51, 121, 1835; "Great or Bath Oolite" (part), Williamson, Trans. Geol. Soc., ser. 2, vol. v., p. 231, 1837; "Brauner Jura γ," Quenstedt, Flözgeb., p. 538, 1843; "Subzone of *Ammonites Sauzei*, ? Zone of *Ammonites humphriesianus*" (part), Oppel, Juraformation, p. 333, 1856; "Fimbria-stage of the Inferior Oolite," Lycett, Cotteswold Hills Handbook, p. 34, 1857; "Zone of *Ammonites Murchisonæ*," (part), Wright, Monogr. Brit. Ool. Echinoderms, pp. 418–433, 1856; "Inferior Oolite Limestone (part), Millepore Bed," Wright, Quart. Journ. Geol. Soc., vol. xvi., pp. 17, 31, 1860;§ "Zone of *Ammonites Sowerbyi*," Waagen, Der Jura in Franken, 1864, and Benecke, Geog. Beitrag, I. p. 507, 1867; Judd, Geol. of Rutland (Geol. Survey), pp. 8, 39, 1875; "Inferior Oolite (part), Millepore Oolite," Phillips, Geol. of Yorksh., p. 35, 1875; "Millepore Series," Expl. 95, S.W. (Geol. Survey), p. 3, 1880.

The lithological character of this series presents two very different phases where exposed on the east and south-west sides of the Yorkshire basin respectively. On the coast these beds are best known under the name "Millepore Series," but in the Howardian Hills and South Yorkshire they have been generally

* The Millepore Bed is probably also contemporaneous with a part of many of the foreign equivalents given for the Grey Limestone on page 228.

† There was considerable confusion at this early date as to the relative position of the Millepore Bed and the Grey Limestone; the former being considered to occupy a higher position than the latter. Both W. Smith and Young and Bird mistook the Oolite of Whitwell (Millepore Series of the Howardian Hills) for the Coral Rag.

‡ This name, which was adopted from the pier at Scarborough being partially built of this rock, appears to have been in general use by W. Smith and others before this time, but this is the earliest publication of it we have been able to discover, although the author is describing another district. The name was used for both the Millepore Bed and the Grey Limestone, which were not distinguished at that time, but considered "according to Mr. Smith the equivalent of the great oolite."

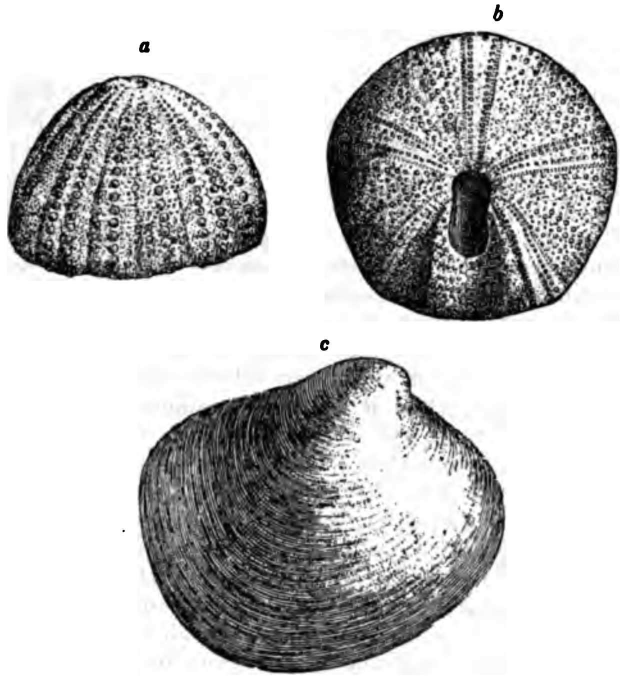
§ In this description of the zones of the Inferior Oolite, Dr. Wright does not make it very clear whether he refers the Millepore Bed to the zone of *Am. Murchisonæ* or *Am. humphriesianus.*

called the "Whitwell or Cave Oolite." As they disappear towards the north it is mainly on palæontological grounds that the two can be correlated.

On the coast this rock is not a true limestone, but has more the nature of a very hard and siliceous calcareous sandstone with ferruginous partings, in fact the exposed situations which it occupies on the shore, and the manner in which it forms as it were a breakwater to the softer strata behind, testifies to its extremely hard nature. It is a false-bedded partly oolitic rock, full of the remains of Polyzoa, Echinodermata, &c., in a fragmentary condition, and has every aspect of having been formed in comparatively shallow water.

FIG. 11.

Fossils from the Millepore Bed.



a, Stomechinus germinans, *Phil.* (after Wright) $\frac{4}{3}$; *b*, Pygaster semisulcatus, *Phil.* (after Wright) $\frac{1}{2}$; *c*, Ceromya bajociana, *d'Orb.* (after Lycett and Morris).

Resting on this hard rock at Yons Nab are a series of marly shales with a few ferruginous bands and some sandstone, which, on account of the fossils that they contain, must be included in this group; they are nevertheless very different from the main mass of the Millepore Series. This upper portion is very local, and has been only observed on the south side of Cayton Bay, where the following section was measured :—

	Ft.	In
Ferruginous sandstone with *Trigonia signata, Avicula, Myacites*, &c. - - - - - -	4	0
Sandy shale with an ironstone band near the base -	4	6
Ferruginous band containing *Pecten clathratus, Pecten articulatus, Avicula braamburiensis, Pholadomya Heraulti, Ostrea*, &c. - - - -	1	0
Sandy shales with fossils in upper part and ripple marks about half way down: *Trigonia* very abundant in this bed, which also contains *Avicula*, spines of *Pseudodiadema*, and remains of plants - - -	7	0
Measures indistinctly seen, principally marly shales,* about - - - - - - -	8	6
Total -	25	0

Below this occur about 15 feet of hard calcareous sandstone with *Entalophora straminea*, the true Millepore bed, forming a reef of rocks extending from the Point across Gristhorpe Bay to the Old Horse rocks.

These beds seem to represent a shallow water deposit, or possibly an alternation of estuarine and marine conditions. Prof. Phillips included the thick bed of sandstone above in this series, but as we could find no fossils in it we have not done so.

On the opposite side of Cayton Bay, at Osgodby Nab† the upper or softer portion of the series seems to be absent, although it may be represented by some 10 or 12 feet of ferruginous sandstone; but as this sandstone appears to be entirely unfossiliferous, it is impossible to offer an opinion. The true Millepore Bed at this place has a maximum thickness of about 20 feet, and is very similar to that in Gristhorpe Bay, the fallen blocks forming a magnificent natural protection to the Point.

North of Scarborough the Millepore Bed does not again appear above the level of the water till we reach the north side of Cloughton Wyke, where it forms a conspicuous reef which is covered at high water. The rock, although more ferruginous, is much less calcareous than to the south, and even what little lime remains seems confined to the upper portion. As we trace the outcrop along the cliffs to the north it becomes even more arenaceous, and about Staintondale nothing remains but a few inches of rotten ferruginous beds with imperfect fossils which finally appear to pass into unfossiliferous sandstones.

Mr. Hudleston considers that the peculiar nature of the Millepore Bed at Cloughton is due principally to subsequent alteration, by which the lime originally in the rock has been in great part replaced by iron. He says, "The fossils have none of their original shell left, nor is this replaced either by calc spar, or by chalybite, but when the rock is fractured, a quantity of snowy-white powder is found lining the cavity, especially about the hinge area, which seems to replace the shell. It is I believe similar in composition to a substance lining the crack of certain septaria of clay ironstone, which contain the ferns previously

* Dr. Wright mentions that Mr. Leckenby collected *Cypris? concentrica*, Bean, from these shales. Quart. Journ. Geol. Soc., vol. xvi. p. 31. *See also* Bean, Mag. Nat. Hist., vol. ix. p. 376.

† Prof. Phillips describes this headland under the name Ewe Nab. Miscalled Yew Nab by Conybeare and Phillips, Outlines of Geology, p. 197.

alluded to. An analysis, which I made of this last winter showed it to consist of—

Water and organic matter	14·40
Silica	45·98
Alumina	38·22
Lime and magnesia	1·50
	100·10

hence it is nearly pure kaolin, and must by no means be confounded with either Scarbroite or Allophane, both of which, though also hydrous silicates of alumina, are very different substances. The rock itself is muddy and ferruginous, partially oolitic in its structure, and contains some grit. The ova and shell fragments appear to be replaced by this kaolin to a considerable extent. There is a very large quantity of carbonate of iron, hardly any carbonate of lime, but there is just sufficient iron peroxidized to impart a reddish-brown tint to the mass. It is frequently charged with carbonized fragments of wood, having the interspaces full of kaolin. The general result is a rock of so peculiar a character that it might be singled out from amongst any number of other rocks. I believe it to be simply an altered oolitic marl, where the lime has been replaced by iron in the mass, and by kaolin-like substance in the shelly parts; the formation of this latter is, in some way, connected with the decomposition of vegetable matter."*

Fossils from the Millepore Bed of the Coast.

ACTINOZOA.

Gonioseris angulata, *Dunc.*
Gonioseris Leckenbyi, *Dunc.*

ECHINODERMATA.

Pygaster semisulcatus, *Phil.*
Pentacrinus vulgaris, *Schlot.*

CRUSTACEA.

Estheria concentrica? *Bean.*

POLYZOA.

Entalophora (Spiropora, Cricopora, or Millepora) straminea, *Phil.*

LAMELLIBRANCHIATA.

Gervillia Hartmanni, *Goldf.*
—— lata, *Phil.*
Lima bellula, *L. & M.*
—— duplicata, *Sow.*
Ostrea, sp.
Pecten aratus? *Waagen.*
—— demissus, *Phil.*
—— saturnus, *d'Orb.*
—— sp.
Pinna cancellata, *Phil.*
—— cuneata, *Bean.*
—— lanceolata, *Sow.*
Astarte minima, *Phil.*
—— recondita, *Phil.*
Cardium Buckmani, *L. & M.*
—— striatulum, *Sow.*
Ceromya bajociana, *d'Orb.*
Cucullæa cancellata? *Phil.*
Goniomya literata, *Sow.*
Gresslya abducta, *Phil.*
Isocardia cordata, *Buck.*
Modiola cuneata, *Sow.*
—— imbricata, *Sow.*
—— Leckenbyi, *L. & M.*
—— ungulata, *Y. & B.* (M. tumidus, *L. & M.*)
Myacites compressiusculus? *Lyc.*
—— decurtatus, *Phil.*
—— oblongus, *Wr.*
—— recurvus, *Phil.*
—— sp.
Mytilus cuneatus, *Phil.*
Pholadomya Heraulti, *Ag.*
—— Sæmanni, *L. & M.*
Pholas costellata, *L. & M.*
Trigonia conjungens, *Phil.*
—— Culleni, *Lyc.*
—— denticulata, *Ag.*
—— hemisphærica, var. gregaria, *Lyc.*
—— recticosta, *Lyc.*
Unicardium gibbosum, *L. & M.*

* Proc. Geol. Assoc., vol. iii. p. 308.

GASTEROPODA.

Actæon Sedgvici, *Phil.* var. pullus, *L. & M.*
Actæonina gigantea, *Desh.*
—— glabra, *Phil.*
Alaria hamus, *Desh.* var. Phillipsii, *d'Orb.*
—— myurus, *Desh.*
Cerithium gemmatum, ? *L. & M.*
—— muricato-costatum, ? *Münst.*
—— vetustum, *Phil.*
Chemnitzia lineata, *Sow.*
Cloughtonia (Phasianella) cincta, *Phil.*
Exelissa weldonensis, *Hud.* (Cerithium comptonense, *Hud.*)
Littorina (Turbo) Phillipsii, *L. & M.*
Natica adducta, *Phil.*
Nerita costulata, *Desh.*
Purpurina (Turbo) elaborata, *Bean.*
Turritella opalina, *Quenst.* var. canina, *Hud.*

From the point where the Millepore Bed first appears it gradually rises in the cliff and may be traced as far as Hayburn Wyke, where it turns inland. It is not very easy to follow its outcrop along these cliffs, but the red ferruginous sandstone of which it principally consists may be seen here and there peeping out from between the vegetation. From this sandstone we obtained *Ceromya bajociana, Modiola imbricata,* and a *Pinna.* At Hayburn, the ground being covered by Boulder Clay, and also probably faulted, the outcrop becomes very uncertain, and can only be inferred from the distance of the beds above.

About half a mile south of Petard Point a little ferruginous sandstone, containing casts of fossils, crops out in the cliff edge; and from this point northwards it may be seen at intervals near the base of the upper cliff. About 500 yards south of Blea Wyke, where the word "Spring" is written on the six-inch map, is the following section:—

	Ft.	In.
Shaly sandstone, very ferruginous - - - -	5	0
Three bands of ironstone in very ferruginous sandy shale	3	0
Sandstone, calcareous at top and very ferruginous throughout, probably - - - - - -	6	0
Total - - -	14	0

The lowest of the three bands of ironstone contains a considerable number of fossils. The chief are *Modiola imbricata, Trigonia recticosta, Unicardium ?, Arca,* and *Cucullæa.*

The upper few inches of the sandstone are so calcareous as to pass almost into a ferruginous sandy limestone. Fragments of crinoids occur in some abundance in a crystalline condition, and give the rocks a semi-crystalline aspect. There are a few species of fossils in this bed, but they are difficult to extract.

A little further north, where a footpath leads up the cliff from "Fox Holes" towards Peak Hall, the following section may be seen:—

	Ft.	In.
Hard yellow sandstone - - - - - -	5	0
Soft yellow calcareous sandstone, with fossils - -	0	2
Hard ferruginous band, many small fossils - -	0	4
Flaggy sandstone, speckled white - - -	1	6
Flaggy sandstone - - - - - -	3	0
Dogger band, speckled white - - - - -	0	6
Soft white sandstone, seems to contain a few casts of fossils - - - - - - - -	2	0
Total - - -	12	6

This bed caps the cliff at the gardens of Peak Hall; and from this point its outcrop takes a direction inland at right angles to the cliff, until meeting the Peak Fault, when it is thrown up to the top of High Moor over the Peak Alum Works. A thin bed of ferruginous sandstone, with a few indistinct casts of small fossils, may be seen in the gutter by the side of the high road from Staintondale to Bay Town; beyond this we have been unable to identify the Millepore Bed.

Further inland we have not been able to recognise this bed with certainty, although in Middle Grain Beck at Darn Holm there is a foot of close-grained ferruginous sandstone with casts of fossils and streaks of soft jet; and again in Winter Gill there is an 8-inch seam of oolite ironstone about 100 feet above the Eller Beck Bed which may represent all that remains of the Millepore Bed on these moors.

In the west and south of the Oolitic area, the Millepore Bed, or Whitwell Oolite as it is better known in this district, first comes in along the western escarpment in the neighbourhood of Kirkby Knowle. On the hill to the north-west of this village there is a peculiar bed of sandstone or white grit, cemented together by crystalline carbonate of lime, which forms a belt round the summit of this outlier. The structure of this rock is very curious, it seems as if a subsequent alteration had been set up in a manner which is very unusual in rocks of secondary age, and that the lime in the stone had been entirely crystallised out by the slow action of solution and redeposition. The quarries in it show the extremely false-bedded character of the rock, and strikingly remind one of the Millepore Bed as seen on the coast. From its position in the hill above the Eller Beck Bed and below the Grey Limestone there can be no doubt that this does represent that bed; and it is certainly the same as the Oolite of Whitwell, which latter has been proved upon palæontological evidence to be the equivalent of the Millepore Bed.*

At the nab end called Wind Egg, to the south-east of Kirkby Knowle, a similar bed may be seen, but in this case there are little shell masses at intervals, in small wedges, mixed up with fragments of Crinoids, &c. This curious rock is continuous only as far as the south point of the hill near Westow Hall.

With the exception of these isolated outcrops the Millepore Bed first becomes traceable as a separate horizon on the outlier of Hood Hill, where it is seen on the south side of that hill at High Ground Barns. The next exposure is in the lane above High Kilburn, where this rock forms the southern end of that outlier, being faulted against the Grey Limestone, and for which it might be easily mistaken. The third and last exposure north of the Coxwold faults is on the three outlying patches at Scencliff Grange. The rock is here somewhat thicker and better exposed than it has been further north and contains the characteristic

* *See* page 215.

Entalophora straminea, which we have found at one or two places.

At the western end of the Howardian Hills the Millepore Bed consists of hard siliceous fossiliferous limestone, in large blocks, which occasionally stand out in large tabular masses overhanging the softer beds below; the lower part of the formation is a much purer limestone and more oolitic, but the oolitic structure does not seem to be always developed to an equal amount. Below the oolite are usually a few feet more of the siliceous beds which towards their base pass into softer sandstone.

The thickness of these beds varies somewhat, in Newburgh Park there is only about 10 feet of them, while at Terrington there must be 20 feet or more, but there is no complete section in which the thickness can be measured.

In the Coxwold area the Millepore Bed is not exposed, being hidden by Drift, and the position of the outcrop is assumed between the other beds. South of these faults it comes on again, and is seen above Newburgh Grange. At Garbut Gill the outcrop is shifted by a fault, and being exposed in several quarries to the south forms a good feature, which may be traced along the escarpment to Oulston. In the quarry below the village here this limestone is worked and the following section was measured:—

Section in Oulston Quarry.

	Ft.	In.
Shaly beds	8	0
Siliceous sandstone	8	0
Shale	1	3
Hard oolitic stone in two beds	4	6
Softer and more shaly beds	2	6
Hard blue limestone partly oolitic on top, weathers brown, base not seen	6	0
Sandstone below.		

The limestone contains *Ceromya bajociana*, *Isocardia cordata*, and other fossils similar to those from the Oolite at Whitwell.

In the faulted ground to the south of Husthwaite there are two outlying patches of this rock capping the hill at Highthorne and Sand Hill.

In Newburgh Park and in the neighbourhood of Yearsley, from there not being much dip, the Millepore Bed crops out both to the north and south, forming a narrow but very extended band along the sides of the numerous valleys intersecting these hills. The beds here consist of two portions, an upper siliceous sandy series and a lower calcareous oolitic series; these latter being much softer and frequently denuded away so that the upper part overhangs in great projecting tables. The lower beds are occasionally burnt for lime; a specimen from Blackdale Plantation was said to contain as much as 82 per cent.

Between Brandsby and Scackleton the strata are uplifted by a large fault, so that the Millepore Bed occurs only as outliers at High Wood and Dalby; east of which the outcrop has a more or less interrupted course by Terrington to Ganthorpe. North of

these villages the outcrop is broken up by numerous small faults into several detached portions; the principal of these is that at Airyholme which extends thence in an uninterrupted line on the north side of the fault to beyond Coneysthorpe. At Ganthorpe the Millepore bed is exceedingly obscure. and appears to be represented by some soft reddish sandstone with calcareous doggers. Further to the east, in Castle Howard Park, these beds become stronger and more calcareous, gradually developing into an oolitic limestone, which forms a good escarpment to the east of the Inn. South of this they are much broken up by numerous faults, but the limestone is quarried at several places, so that sections are frequently exposed about Bulmer, Welburn, and at several points along Cram Beck.

Near Bulmer the limestone, which has a very Rag-like aspect, contains corals,—an interesting fact, tending to show that when the oolitic structure is developed in the rock, the presence of corals may be expected. In this neighbourhood also we had the good fortune to discover a specimen of *Entalophora straminea*, this and Kilburn, mentioned above, being the only instances in which we have been able to obtain the characteristic fossil from inland localities, although it occurs plentifully on the coast.

In the neighbourhood of the Derwent the Millepore Bed attains its finest development, and is well exposed in the quarries at Mount Pleasant near Whitwell, where it has been worked for a number of years. This is the typical section from which the name "Whitwell Oolite" was derived, and from which most of the fossils have been obtained. As pointed out by Dr. Wright the Oolite of Whitwell more nearly resembles in lithological character the thick-bedded freestones of the Inferior Oolite of Gloucestershire than any other rock in Yorkshire. It is a thick-bedded oolitic limestone, usually blue centered, and much resembling some of the beds of the Coralline Oolite, for which it was originally mistaken; it is, however, more ferruginous, and the different assemblage of fossils at once distinguishes it from that formation.

There are from 20 to 30 feet of oolitic limestone in these quarries, the lower beds of which are used for road-metal, while the upper more regular beds are burnt for lime. Above this is an upper series consisting of sands and siliceous limestones which have a thickness of about 20 feet; these beds often weather out into roundish balls or doggers and large tabular slabs as may be frequently observed in the Castle Howard district. In Cram Beck the lower part of these sands is more clayey and contains beds of very fine potters earth, which Mr. Hudleston mentions was much used by the Romans; the remains of the kilns and quantities of old ware having been found in making excavations for the Reformatory close by. Throughout the Howardian Hills these silicious limestones and sands are really more constant than the purer beds below; but it is only in the neighbourhood of the Derwent that the two series can be separated. The fauna of these upper beds, as would be expected, appears to be rather different

from that of the oolite, but scarcely a sufficient number of species have been collected to draw much inference from them, except that Brachiopoda are rather more plentiful.

On the east side of the Derwent the whole of this series is well developed about Westow, where the two divisions of the rock are very distinct as far as Jenny Milner Grange. At the latter place they are cut out by a large east and west fault, so that when they appear again at Burythorpe, the division into two beds cannot be made out. In a quarry at the side of the beck about 300 yards north of Jenny Milner Grange there is a curious section showing quite an unconformity between the lower beds of limestone and the sandstone above; the former dipping about 15 degrees to the south while the latter incline at about 10 degrees to the north. Of course this unconformable junction is only local, but it serves to show the extremely false-bedded character of these strata.* At Burythorpe owing to numerous small faults, the limestone is broken up into several patches, but south of Leavening the outcrop becomes more continuous, and may be traced along at the foot of the Wolds by Acklam to Kirkby Underdale. The bed is here, however, very thin and being frequently overlapped by the Chalk, it is only here and there that it can be seen. At the latter place the limestone forms an outlier on the hill near the village; it is also exposed at Great Givendale, having been quarried near Grimthorpe House. There are also two small faulted outliers near Whitwell and Gally Gap.

The following fossils have been obtained from the Whitwell Oolite, or from the sandy beds associated with the same.

Fossils from the Millepore Bed inland, principally Whitwell and Cram Beck.

ACTINOZOA.

Calamophyllia radiata, *Lamx.*
†Gonioseris angulata, *Dunc.*

ECHINODERMATA.

Clypeus Michelini, *Wr.*
Holectypus depressus, *Leske.*
Hyboclypus (Galeropygus) agariciformis, *Forbes.*
Pseudodiadema vagans? *Phil.*
†Pygaster semisulcatus, *Phil.*
Stomechinus bigranularis, *Lam.*
—— germinans, *Phil.*

ANNELIDA.

Vermicularia nodus, *Phil.*

CRUSTACEA.

Goniochirus, sp.

POLYZOA.

†Entalophora (Spiropora, Cricopora) straminea, *Phil.*

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* This is probably the place alluded to in Greenough's Geology 1819, p. 14; where it is said, "At Westow, five miles from Malton, may be seen horizontal beds of oolite resting on highly inclined ones."

† The species marked thus have been found in the Millepore Bed of the coast.

BRACHIOPODA.

Acanthothyris (Rhynchonella) Crossi, *Walker*. (South Yorks.)
—— spinosa, *Schlot.*
Terebratula globata, *Sow.*
Terebratula maxillata, *Sow.* var. submaxillata, *Morris.*
Waldheimia bullata, *Sow.*

LAMELLIBRANCHIATA.

Gervillia acuta, *Sow.*
*—— Hartmanni, *Goldf.*
Gryphæa sublobata, *Desh.*
Hinnites abjectus, *Phil.*
—— tumidus, *Ziet.* (H. velatus, *Goldf.*)
*Lima bellula, *L. & M.*
*—— duplicata, *Sow.*
—— interstincta, *Phil.*
—— pectiniformis, *Schlot.* (proboscidea, *Sow.*).
—— punctata, *Sow.*
Ostrea flabelloides, *Lam.* (O. sulcifera, *Phil.*).
*Pecten aratus?, *Waagen.*
—— lens, *Sow.*
—— personatus, *Goldf.*
*—— saturnus, *d'Orb.*
*Pinna cuneata, *Phil.*
Pteroperna plana, *L. & M.*
*Cardium Buckmani, *L. & M.*
*Ceromya bajociana, *d'Orb.*
Cucullæa elongata, *Sow.*
Cypricardia bathonica, *d'Orb.*
—— cordiformis, *Desh.*
*Isocardia cordata, *Buck.*
Lucina bellona, *d'Orb.*
*Modiola imbricata, *Sow.*
*—— ungulata, *Y. & B.*
*Pholadomya Sæmanni, *L. & M.*
*Trigonia conjungens, *Lyc.*
*—— denticulata, *Ag.*
—— duplicata, *Sow.*
—— gemmata, *Lyc.*
*—— hemisphærica, var. gregaria, *Lyc.* (South Yorks.)
——pullus?, *Sow.*
*—— recticosta, *Lyc.*
—— tenuicosta?, *Lyc.*

GASTEROPODA.

Natica cincta, *Phil.*
Nerinæa, sp.

PISCES.

Asteracanthus ornatissimus, *Ag.*
Ischyodus, sp.
Strophodus magnus, *Ag.*

Only nineteen of the above species have, as far as we know, been found on the coast, but the occurrence of such fossils as *Entalophora straminea*, *Pygaster semisulcatus*, and *Stomechinus germinans* is sufficient to indicate its position, and to correlate it as Dr. Wright has shown with the typical Millepore Bed of Scarborough and Cloughton, even if its identity were not satisfactorily established on stratigraphical evidence.

In South Yorkshire, the limestone which is the equivalent of the Millepore Bed, or as it is there called the Cave Oolite, is the principal and best known of all the Jurassic rocks in that part of the country. It consists of a soft white Oolite which is hard and blue-centred when first quarried, but decomposes on exposure to the air, or to water conveying carbonic acid, into a friable oolitic sand. This is noticeable in many old quarries, particularly near Newbald, where most of the rock, which at one time must have been good limestone, is now a soft oolitic sand. The upper part of the rock is usually flaggy and false-bedded, as may be seen in the quarries about South Cave and in the Humber at Brough.

The Limestone, which has a thickness of from 20 to 30 feet, or perhaps rather more, crops out immediately below the Red Chalk

* The species marked thus have been found in the Millepore Bed of the coast.

to the east of Market Weighton; and, crossing the road north of Mask Hall, continues along the hillside to Sancton, where it has been rather extensively quarried, but these quarries are now filled in, and there being a good deal of superficial sand, its course through the village is obscure.

Prof. Blake and others consider that the strata here are faulted, but we could find no evidence of this; and the different beds, although dipping rather strongly to the east, are at about the same level on both sides of the little valley crossing the village.*

At Newbald, where the Limestone again comes out from the overlap of the Chalk, it forms a considerable spread, and has been largely quarried to the west of the village.

In the hollow half a mile south of South Newbald the outcrop may be broken by a small fault; but as a slight roll of the beds would cause the little irregularity observed here, we have not shown one. Between here and Cave the limestone again spreads out into a good feature a quarter of a mile or more in breadth. It has been extensively quarried in this district, and a clear section is shown in the railway cutting, from which Messrs. Keeping and Middlemiss mention the following species: *Trigonia conjungens, Lima pectiniformis, Hyboclypus*, and *Spiropora straminea*.†

In a well at the cross roads half a mile north of South Cave, the rock, which is 20 feet thick, was met with at a depth of 49 feet.‡ The outcrop which crosses the Park is rather more obscure, but south of this it again forms a good feature, and may be traced above the village of Ellerker uninterruptedly to within above 400 yards of Brough. In this part of its course the limestone has also been largely quarried, although much covered by superficial gravels, which at Brough itself are of great thickness. The stone from these quarries was used in the construction of the Hull docks, and in earlier times for the monasteries of Holderness. From 14 to 18 feet of limestone were met with in the shaft near Ellerker, of which an analysis is given on page 471.

In the boring near Brantingham Grange there were nearly 30 feet of limestone, and the cores below this were also excessively calcareous, and very much resembled some of the beds seen at the Kirton Tunnel quarry in Lincolnshire, where they are worked for cement, and have been classed with this rock.

The limestone, although entirely hidden at Brough for the space of nearly a mile, appears again in the bed of the Humber, where it forms the reef of rocks known as Brough Scalp.

* The Yorkshire Lias, p. 208, and map.
† Geol. Mag., dec. II., vol. x. p. 216.
‡ *See* p. 259.

CHAPTER VIII.

THE LOWER OOLITES—(*continued*).

MIDDLE ESTUARINE SERIES.

Synonyms.—"Sandstone, Shale, and Coa " (part), Young and Bird, Geol. of the Yorksh. Coast, p. 109, 1822 ;* "Lower Sandstone, Shale and Coal" (part), [District north of Scarborough], and "Upper Sandstone Shale and Coal" (part), [District south of Scarborough], Phillips, Geol. of Yorksh., p. 33, 1829;† "Middle Series" (Middle Sandstone and Shale), and "Great or Bath Oolite" (part), Williamson, Trans. Geol. Soc., ser. 2, vol. v., pp. 234, 237 ; "Lower Sandstones and Shales" (part), Wright, Quart. Journ. Geol. Soc., vol. xvi., p. 30, 1860; also Leckenby, vol. xx., p. 75, 1864 ; "The Middle Shale and Sandstone," Hudleston, Proc. Geol. Assoc., vol. iii., p. 310, 1874 ; "Middle Estuarine Series," Expl. 95, S.W. (Geol. Survey), p. 5, 1880.

IT is not always possible, as we stated previously, to separate this Estuarine Series from that below the Millepore Bed ; consequently it is only on the coast and in the Howardian Hills that we can accurately define its limits. For this reason, its outcrop across the north having been included with the Estuarine Series already described, we need here only touch upon these remaining districts.

It was a curious fallacy in the earlier descriptions of the coast section, that these estuarine beds were thought to be only a local intercalation between the Grey Limestone and the Millepore Bed, the then supposed equivalent of the Great Oolite.

These beds in Gristhorpe Bay, although not much more than from 30 to 40 feet thick, have attracted considerable attention from the fact of their containing a large series of plant remains, many of which are in a fine state of preservation.

In the cliff at Yons Nab at the west end of Gristhorpe Bay, where these beds first rise from the shore, they consist of an alternating series of thin bands of sandstone and shale with streaks of coal.‡

* The Middle Estuarine Series of Gristhorpe was included in the "Ironstone and Sandstone."

† The whole of the Estuarine beds at Gristhorpe were included in the "Upper Sandstone Shale and Coal," in the first and second editions, but this was corrected in the third edition, 1875.

‡ This section has been measured and described by several authors, first by Phillips in 1829, by Williamson in 1837, by Morris in 1853, again by Phillips in 1857, by Wright in 1859, by Hudleston in 1874, for a third time by Phillips in 1875 for the new edition of the Geology of the Yorkshire Coast, and lastly by ourselves in 1879 for the Explanation of the Geological Survey Map, 95 S.W. ; the strata have also been studied by Lycett, Leckenby, Judd, and others.

Section measured East of the Point in Gristhorpe Bay.

	Ft.	In.
Sandstone with fine black laminations, very characteristic	5	0
Shale	8	0
Black coaly shale	0	3
Soft white sandstone, with rootlets	1	0
Grey shale	5	0
Sandstone and shale with carbonaceous markings, and some sulphur	3	6
Black shale	1	6
Finely laminated sandstone	1	6
Finely laminated shale, with irregular patches of coal and fossil plants	6	0
False-bedded sandstone, with pyrites and carbonized wood, passing into hard sandstone towards the base	21	0*
Total	52	9

Section measured West of the Point, Low Red Cliff.

	Ft.	In.
Laminated sandstone	4	6
Shale	6	0
Sandstone	1	0
Shale	2	0
Sandstone, with rootlets and coaly streaks	3	0
Irregular sandstone and shale	2	0
Sandstone	2	0
Shale. Thin irregular ironstone band near the top	2	0
Sandstone with carbonaceous markings. Plant bed?	2	0
Shale	3	6
Massive sandstone	4	0
Shaly sandstone	2	0
Total	34	0

In the shales just over the thick sandstones in the lower part of the first of these sections the celebrated Plant-bed of Gristhorpe occurs, which has afforded so rich a harvest to the Palæobotanist.

The true position of the Gristhorpe plant-bed was first pointed out by Prof. Williamson in his detailed account of the strata along the coast. Since which the flora of this bed have been figured and described by several authors; these results are ably summarized by Prof. Phillips in the last edition of the "Geol. of the Yorkshire Coast," from which account the following list of plants from Gristhorpe and Cloughton is taken† :—

List of Plants from the Middle Estuarine Series.

Cryptogamia (Varia).

Equisetum columnare, Br.	Gristhorpe, Cloughton.‡
Fucoides arcuatus, L. & H.	Gristhorpe.
—— *erectus*, Bean	Gristhorpe, Cloughton.
Lycopodites falcatus, L. & H.	Cloughton.‡
Phyllotheca (Equisetites) lateralis, Phil.	Gristhorpe, Cloughton.

* The greater part of this bed probably belongs to the upper portion of the Millepore Series, although no fossils were observed at this point.

† The species given in this list are revised from the work of later authors. *See* page 181.

‡ Mr. Leckenby says these species have not been found above the Millepore Bed, —*Quart. Journ. Geol. Soc.*, vol. xx. p. 76.

CRYPTOGAMIA (FILICES).

Acrostichites princeps, Presl. (*Sph. modesta* Bean)	Gristhorpe, Cloughton.
—— *Williamsonis*, Br. (*Pecopteris recentior*, Phil.) -	Gristhorpe, Cloughton.
Dicksonia (*Sphenopteris*) *nephrocarpa*, Bunbury -	Gristhorpe.
Dictyophyllum (*Phlebopteris*) *Leckenbyi*, Zign. -	Gristhorpe.
—— *rugosum*, L. & H. (*Ph. Phillipsii*, Br.) -	Gristhorpe, Cloughton.
Pecopteris acutifolia, L. & H. - - -	Gristhorpe, Red Cliff.*
—— *arguta*, L. & H. (*P. lindleyana*, Presl.) -	Gristhorpe, Cloughton.
—— *cæspitosa*, Phil. - - . -	Gristhorpe.
—— *curtata*, Phil. - - - - -	Gristhorpe.
—— *dentata*, L. & H. - - - -	Gristhorpe, Cloughton.
—— *denticulata*, Br. - - - -	Gristhorpe
—— *exilis*, Phil. (*P. Phillipsii*, and *Sph. serrata*, L. & H.).	Gristhorpe.
—— *lobifolia*, Phil. - - - -	Gristhorpe, Cloughton.
—— *undans*, L. & H. - - - -	Gristhorpe.
—— *undulata*, Phil. - - - -	Gristhorpe.
Phlebopteris contigua, L. & H. - - -	Gristhorpe.
—— *polypodioides*, Br. - - - -	Gristhorpe.
—— *Woodwardii*, Leck. - - - -	Gristhorpe, Cloughton.
Sagenopteris (*Otopteris*) *cuneata*, L. & H. - -	Gristhorpe.
—— (*Glossopteris*) *Phillipsii*, Br. - - -	Gristhorpe.
Sphenopteris arguta, L. & H. (*Sph. denticulata*, Br.)	Gristhorpe, Cloughton.
—— *Williamsonis*, Br. - - - -	Gristhorpe.
Tæniopteris major, L. & H. - - -	Gristhorpe, Cloughton.
—— *ovalis*, Sternb. - - - -	Gristhorpe.
—— *vittata*, Br. - - - - -	Gristhorpe, Cloughton.
Thyrsopteris (*Sphenopteris*) *murrayana*, Br. -	Gristhorpe, Cloughton.

GYMNOSPERMÆ (CYCADACEÆ).

Anomozamites lindleyanus, Schimp. (*Pterophyllum Nilssoni*, L. & H.).	Gristhorpe, Cloughton.
Baiera longifolia, Phil. - - - -	Gristhorpe.
—— *microphylla*, Phil. - - - -	Gristhorpe.
Beania gracilis, Carr.† - - - -	"Oolite Shale of Gristhorpe."
Otenis falcata, L. & H. - - - -	Gristhorpe.
Cycadites zamioides, Leck. - - - -	Gristhorpe.
Nilssonia angustifolia, Bean - - -	Gristhorpe.
—— *compta*, Phil. - - - -	Gristhorpe, Cloughton.
—— *mediana*, Bean - - - -	Gristhorpe, Cloughton.
—— *tenuicaulis*, Phil. - - - -	Gristhorpe.
—— *tenuinervis*, Nathorst. - - - -	Cloughton.
Otozamites acuminatus, L. & H. - - -	Gristhorpe.‡
—— *Beanii*, L. & H. - - - -	Gristhorpe, Cloughton.
Ptilozamites (*Odontopteris*) *Leckenbyi*, Bean. -	Gristhorpe.
Solenites murrayana, L. & H. - - -	Gristhorpe, Cloughton.
Williamsonia (*Pterophyllum*) *pecten*, Phil. - -	Gristhorpe.

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* Prof. Phillips gives this species from "the upper shale, under Red Cliff," on the authority of Dr. Murray; but Mr. Leckenby includes it in the list from the "Lower Sandstones and Shales" (Mid. Est.) of Gristhorpe.

† This Cycadean Fruit is inserted on the authority of Mr. Carruthers. It is probably the same as that figured by Phillips in the Geology of the Yorkshire Coast, 3rd edit., p. 233, as *Sphæreda paradoxa*, L. & H., but the former author has pointed out the cause of this error.—Geol. Mag., 1869, p. 98.

‡ Mr. Leckenby says this species has not been found above the Millepore Bed.

mining was formerly carried on at Gate Holm Wood and High Normanby in the Hawsker district, and on a smaller scale at Cloughton Wyke, and other places.*

Except at Hayburn, where they have been removed by denudation, these beds are well seen all along the cliffs from Cloughton to the Peak. In the cliffs here just above Blea Wyke there is the following section:—

Section of the Middle Estuarine Series, Blea Wyke.

	FT.	IN.
Dark shale, coaly at base	2	6
White rubbly false-bedded sandstone with shale partings	40	0
Hard white sandstone with *Equisetites*	3	0
White shale with carbonaceous band at top	20	0
COAL SEAM	0	10
Shale	3	0
Sandstone, hard and white	3	0
Total	72	4

Millepore Bed at base.

This is probably an under-estimate of about 15 feet, too much having been allowed for the slight slope of the cliff. The bed of sandstone above is usually included in the Middle Estuarine Series; but here it is so unmistakably marine that we have included it in the Grey Limestone Series.† If this bed of sandstone were added, the total of the Middle Estuarine Beds would be nearly 100 ft.

North of the Peak and also inland across the northern outcrop, from the dying out of the Millepore Bed, this division of the Estuarine Serie scannot be separated from that below, and its further extension has been described under that head. For this reason in the cliffs at Hawsker we cannot fix a base to the series. The beds immediately under the Grey Limestone in this district consist principally of shales with thin sandstones, soft jet, and thin coal seams, but they are scarcely ever well exposed inland.

Towards the southern end of the western escarpment this series may be again separated from that below by the coming in of the Millepore Bed, although the beds are not sufficiently well exposed to allow of a line being drawn between them, except on the outlier at Kirkby Knowle and those near Kilburn. The only clear exposure of these beds is below the great section in the Grey Limestone Series at Brockholes near Kirkby Knowle, where they are seen to consist of alternations of shale and massive beds of sandstone some of which are quarried.‡

Throughout the Howardian Hills the Middle Estuarine Series are on the whole very sandy, and form very poor ground which requires to be well marled to bring it into cultivation. The

* An inferior variety of Jet is now imported from Spain, which, from the cheap rate at which it can be obtained, has superseded the "soft" or "Oolite jet."

† *See* page 233.

‡ *See* page 246.

upper part is more clayey, and at Grimston has been dug for spreading over the sandy ground below.

The following section, which has a very coal-measure aspect, was measured at this place.

Marl Pit, Grimston Moor.

	Ft.	In.
Little sandstone (irregularly bedded) - - - -	—	
Brown shale - - - - - - - -	2	0
Dark shale with sandy streaks - - - - -	0	8
Light-coloured sandy shale, with a little sandstone here and there - - - - - - - -	4	6
Dark carbonaceous shale - - - - - -	0	4
White sandy clay with vertical stigmaria - - -	0	10
Hidden by talus - - - - - - -	4	0
Thin seam of coal on floor of working - - - -	—	

The total thickness of these beds appears to be about 60 feet; they form large spreads in Newburgh Park, and on Grimston Moor, but thin away to the eastward, and near Terrington are not more than from 30 to 40 feet thick.

East of this they form a mere sandy division between the more important limestones; and in some cases merge into them so gradually that it is difficult to separate one from the other.

In the neighbourhood of the Derwent these beds crop out in the lower part of Stonecliff Wood, and on the opposite side of the river in Firby Wood. They consist principally of soft sandy rock with apparently lenticular patches of shale or clay. They are only about 20 feet thick in this region and are said to contain a few dwarfed shells principally *Ostrea* and *Avicula*, as if a portion of the fauna from the limestone below were struggling through the adverse conditions which prevailed between the deposition of the Millepore Bed and the Grey Limestone.

This is the last that is clearly seen of these beds; east of Derwent, partly from the faulted character of the ground and partly from the dying out of the Grey Limestone, or from its merging with the limestone below, these beds cannot be traced beyond Westow as a separate division.

Coal Seams.—The Middle Estuarine Series is the principal coal-bearing horizon of the Lower Oolites; for with the exception of one or two thin seams near the base of the Lower Estuarine beds, and which we have already described with that series, the only workable coal is found within 100 feet more or less of the base of the Grey Limestone, and, therefore, occurs in beds which belong to this horizon, although in mapping we are unable to separate them from the Lower Estuarine Series.

These coals have been principally wrought along the north side of the Esk, over the moors to the south of that valley, and in the Howardian Hills at Coxwold and other places.

Along the Coast a seam of coal first comes in at Cloughton Wyke which was formerly worked at the edge of the cliff, but never to any great extent. There is no trace of these workings now, but it is probably the "shaly coal" 6 inches thick given in the section on page 221 that is referred to. Young and Bird,

writing at a period when coal was much dearer in this district than it is at present, state that this coal is so thin, that, unless it is very easy of access, it will scarcely repay the expense of working.*

About Hayburn Wyke and along the Staintondale Cliffs this coal is not well seen, but in the section over Blea Wyke it is again exposed and is about 10 inches thick.†

‡In the Ruswarp boring§ two thin coals are mentioned towards the upper part, but it is not very clear whether either of these is the seam which is seen in the cliff or that has been worked inland at various places; if it is the same bed the thickness of the Estuarine strata between it and the Grey Limestone is rather greater here than elsewhere.

At Maybecks a coal seam occurs which is about 10 feet below the Grey Limestone; this is probably the bed which has been worked, and which is stated to be only 6 inches in thickness. This seam appears to occur at a higher horizon than any other with which we are acquainted and must be above the thin coals mentioned in the boring here, although we are not quite sure of the position of this boring.||

A seam occurs again on the opposite side of the hill in Eller Beck, but at a greater distance below the Grey Limestone; it crops out for a short distance above Walk Mill Force, where a few pits have been sunk to it; and the beds above, which consist principally of shales with plant remains, may be well studied in the banks of this stream. This coal was worked about the end of the last century, and is stated by Young and Bird to have been "above two feet thick, being the greatest known in the district; but this was found to be merely an accidental swell of the coal stratum, which was soon exhausted."¶ A thin seam of coal a few inches in thickness is stated to have been met with in a boring put down by Stephenson in Newton Dale about 1835, which was carried to a depth of 193 feet.**

In the North Cleveland hills it has been proved by mining that this seam of coal is often cut out by a bed or wedge of sandstone; and, although it was probably originally deposited over the whole of this area, it is now found only at a few places principally in the north-west and south.

In the Easington district two borings passed through the Moor Grit to the *Ironstone* of the Middle Lias, but apparently without meeting any coal seam.

In Kilton Pit two seams, one 6 inches and another 5 inches, are recorded; but, from the depth below the Grey Limestone

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* Young and Bird.—Geol. Survey of the Yorksh. Coast. 2nd ed., p. 115.

† *See* page 222.

‡ Most of these particulars are taken from the account given by Messrs. Barrow and Reid, Memoirs of the Geological Survey, Explanations of 95 N.W., 96 N.E., and 104 S.W.

§ *See* page 185.

|| *See* page 187.

¶ Young and Bird.—Geol. Survey of the Yorksh. Coast. 2nd ed., p. 121.

** Bewick, Geol. Treatise, p. 172.

Series, it is doubtful if either of them represent this seam. There is no mention of it in North Skelton Pit; though too much reliance must not be put on this, as the account of the strata was not carefully kept. On Skelton Hill it is again found having been worked at the east end near Trout Hall, while borings put down by Messrs. Bell Brothers proved its extension under the west end of the hill. South of this it has been dug at the outcrop near Groundhills Head, and was exposed in removing the bearing from a quarry on the hillside above Margrove Park, at the north end of Stanghow Moor, a very unusual circumstance. It was also proved in a small boring near Jenny Frisk Well. Over a large part of the interior of these hills this coal seam appears to be absent, for in a deep boring put down on Girrick Moor it is not mentioned, neither was it found in Dodd's borehole at Girrick, nor in Lingdale Pit.

In the valley of the Esk the coal crops out along the higher part of the bank between Danby and Lealholm Bridge. It is well exposed in a gully near Lop Hall above Danby Station where the following section, which gives a fair view of the nature of this part of the Estuarine Series, was measured :—

		Ft.	In.
Grey Limestone Series.	Soft encrinital sandstone	2	0
	Sandy ferruginous shale	4	0
	Hard silicious and ferruginous sandstone with *Gryphæa*, &c.	8	0
Shaly sandstone		10	0
Blue and white shale		3	0
Soft carbonaceous sandstone		5	6
Fireclay		3	0
Sandy shale		2	6
Soft, brown, micaceous sandstone		14	0
Grey shale		5	0
Bluish-grey sandy shale		4	2
Flaggy sandstone		4	6
Coal Seam	Coal 7½ ins. Shale 5½ ,, Coal 6 ,,	1	7
Underclay		1	3
Shaly sandstone with vertical *Equisetites*		1	6
Sandy shale		3	0
Sandstone		2	6
Shale with jet or pipecoal		15	0

The coal has been largely worked in this neighbourhood, but it is of poor quality and consequently is principally used for lime burning. Young and Bird give the greatest thickness of the seam as 17 inches, and state that from 200 to 300 bushels per day on an average were obtained from these pits. Across the hill between Lop Hall and Doubting Castle there are several old pits, but none along the line of outcrop between these places, which seems to imply that the seam is poor at the edge, but becomes better further in. From the head of Clither Beck near Doubting Castle, the outcrop may be followed by Poverty Hill, where the coal was being worked at the time of our survey, to Oakley Walls below Danby Beacon, having been also worked at both

these places. Below Walls End the coal is again seen for a short distance, but cannot be traced further east on this side of the valley.

On the south side of the Esk Valley the coal has been worked in the early part of this century at Wintergill, on Glaisdale Ridge, at the head of Fryup Dale,* and at the head of Danby Dale; and the outcrop may be traced fairly well between these places, although the coal itself is only seen in a few imperfect road-sections on either side of Fryup Dale and on Westerdale Moor. South of this latter the outcrop runs round to the south, and has been somewhat extensively worked on the moors above. On Blakey Moor the thickness of the coal varies from 8 to 12 inches, but near Blakey House it swells out to a maximum of 2 feet, although at the head of Rosedale there is not more than 15 inches, while in the Castleton Road shaft of the Rosedale East Mines there is as much as 18 inches. Further east this bed has been worked at Hamer and above Hazel Head, there being an inlying outcrop of the coal in the beck to the north of the former place, and the coal itself is seen on the road just above.

About Ingleby, where as a rule only the lower portion of the beds above the Eller Beck Ironstone are present, the strata are much more arenaceous, and there is no evidence of the coal being present. Towards the lower end of Bilsdale, however, on the west side above Wether Cote, and also on the East Moors, this coal has been extensively mined; it is seen in Bogmire Gill just below Hazel Green, north of which its course may be fairly well made out both by the position of the Limestone above and the various coal pits, the latter being very numerous about Old Kiln and Piethorn. From information, the coal here is in two beds 11 inches and 4 inches thick respectively, and about 60 feet below the Grey Limestone Series

At Harland, to the south-west of Farndale, this coal has been largely worked. It is here only 8 or 9 inches thick, but is better for house purposes than that at Piethorn.

West of Bilsdale the coal crops out about 50 feet below the Grey Limestone Series on either side of Ladhill Beck. It is here about 10 inches thick, and lies beneath a bed of sandstone which forms a good roof to the workings. There are also several old coal pits along Stonymoor Sike, the northern branch of the Rye near Coal Ridge; an adit has been made to the coal here, and fragments of it are seen in the road going to Skelbeast Crag. It again seems to have been met with, as we have mentioned in the boring on Osmotherley Moor and in the hollow to the north-east of Nether Silton, there being several old adits in the lower part of Swinestone Cliff Plantation. Some old coal pits may be observed in the bank east of Kepwick, and there are indications of a coaly seam at one or two places along the escarpment to the south.

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* Young and Bird state that at the head of Fryup Dale the coal was 16 inches thick.

South of the Hambleton Hills this coal has been worked on the outlier above Kilburn; but the principal workings were between the faults near Burtree House north of Birdforth, at Coxwold, and in Newburgh Park; at the latt r place Mr. Winch gives the following section:—

Section of the Engine pit in Newbury Park Colliery, the seat of the late Lord Falconberg, near the village of Coxwold, Yorkshire.

	Ft.	In.
Soil - - - - - - - - -	6	0
Blue metal - - - - - - - -	4	6
Soft blue metal - - - - - - -	30	0
Strong grey metal with catheads - - - -	1	0
Coarse strong grey post - - - - - -	7	0
Coal - - - - - - - -	1	4
Total - - -	49	10

The seam of coal is of irregular thickness, seldom under 10, but usually about 16 inches. It dips to the east 2 or 3 inches per yard. The coal is of an inferior quality.

At Birdforth, where the coal was worked about the year 1760, there were two seams, the lower of which is said to have been from 3 to 4 feet thick, and at about from 25 to 30 yards below the surface, but dipping rapidly in a north-west (east?) direction; it could only be found over an area of about a quarter of a mile.

A thin coal is seen in the Marl Pit on Grimston Moor, which is probably the equivalent of this seam, but this is the only other place that we have found it in the Howardian Hills. The seam worked in the valleys between here and Gilling is, as we have mentioned, apparently a lower bed than that in Newburgh Park.

CHAPTER IX.

THE LOWER OOLITES—*continued.*

SCARBOROUGH OR GREY LIMESTONE SERIES.

THIS, which is the most important marine series of the Lower Oolites, was originally called "Pier Stone" from the fact of its being used in the construction of the harbour pier at Scarborough. Young and Bird describe the bed under the name "Blue Limestone," but they did not recognise the important outcrop south of Scarborough, although their account of the interior is more detailed than any other. Phillips, who included this and the Millepore Series in the Bath Oolite formation, in his earlier editions speaks of it under the general term "Oolite," although that of "Gray Limestone" is also used.* Williamson calls it the "Great or Bath Oolite," apparently following the general notion at that time that it was the equivalent of these beds in the South of England, although he says that the characteristic shells of the Great Oolite are few, and that they have a general resemblance to the Inferior Oolite. Wright, who writes of this bed as the "Grey Limestone," was the first author who really pointed out its true position, and that it occupied a distinct horizon above the Millepore Bed. The term Scarborough Limestone is first used by Hudleston.

Synonyms and Foreign Equivalents.—"Blue Limestone," Young and Bird, Geol. Survey of the Yorkshire Coast, p. 96, 1822, p. 100, 1828; "Pier Stone" (part), Murchison, Geol. Trans., 2nd ser., vol. ii., p. 297, 1829;† "Gray Limestone or Oolite" (part), also "Oolite of Lincolnshire and Bath Oolite" (part), and "Brandsby Roadstone," Phillips, Geol. of Yorksh., pp. 33, 149, 1829; pp. 3, 121, 1835; "Great or Bath Oolite" (part), Williamson, Trans. Geol. Soc., ser. 2, vol. v., p. 231, 1837; "Eisenrogenstein (part) und Walk-Erde Gruppe," Fromherz, Die Juraformation des Breisgaues, pp. 13–17, 1838; "Brauner Jura δ" Quenst., Flozgeb, p. 538, 1843; "Blauer Kalke, Korallenschicht, Giganteusthone und Ostreen-kalk," Quenst., Pfizenmayer, deutsche geol. Gesellsch, vol. v., t. 16, 1853; "Calcaire ferrugineux," Terquem, Pal. du Dep. de la Moselle, Statistique extr., p. 25, 1855; "Die Schichten des *Ammonites humphriesianus*" (part), Oppel, Juraformation. p. 333, 1856; "Zone of *Ammonites humphriesianus,*" Wright, Monogr. Brit. Ool. Echinoderms, pp. 418–433, 1856; "Zone of *Ammonites humphriesianus* (part), Inferior Oolite (part), Grey Limestone," Wright, Quart. Journ. Geol. Soc., vol. xvi., p. 17, 1860; "The Scarborough Limestone, the Stonecliff Wood Series," Hudleston, Proc. Geol. Assoc., vol. iii., pp. 311, 324, 1874; "Zone of *Stephanoceras humphriesianum,*" Wright, Monogr. on the Lias Ammonites, p. 154, 1879; "The Scarborough or Grey Limestone Series," Expl. 95, S.W. (Geol. Survey), p. 7, 1880; "Scarboroughin," Mayer-Eymar, Cours de Stratigraphie, 1888.

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* In the edition of 1875 (Edited by R. Etheridge) the term "Grey Limestone Series" is adopted (p. 111).

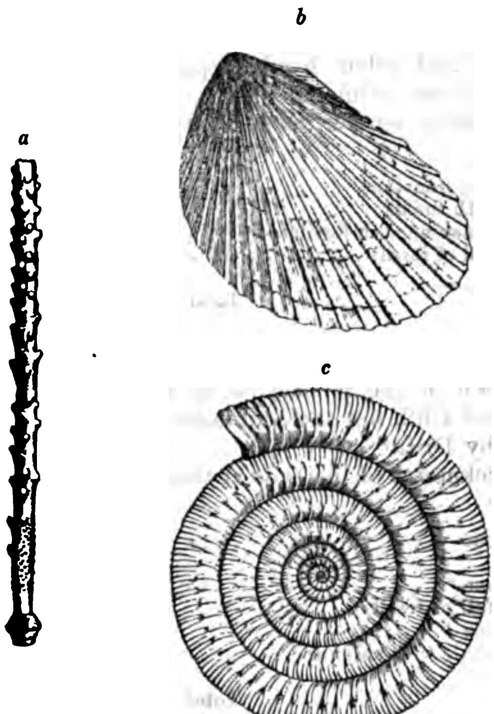
† *See* note, p. 206.

This rock is much in want of a good descriptive name, but it has already received so many that we hesitate to give it another. The terms "Grey or Scarborough Limestone" are not very appropriate as it really consists of several alternations of strata of different lithological character which are not always grey, and in which there is little that is really limestone; the majority of the beds being calcareous shales and sandstones, and in some places even coarse grits.

The general character of this rock is very variable. To the south of Scarborough it consists principally of calcareous shales with thin nodular ironstones, and a little calcareous sandstone; these latter towards the north become more prominent and over the interior moorlands develop into massive beds of coarse sandstone; while to the south in the Howardian Hills they pass into fine-grained flaggy sandstone, and finally die out altogether.

FIG. 12.

Grey Limestone Fossils.



a, Spine of Rhabdocidaris maxima, *Münst.* (after Wright) $\frac{2}{3}$; *b*, Avicula braamburiensis, *Phil.* (after Lycett and Morris) 2; *c*, Ammonites humphriesianus, *Sow.* (after d'Orbigny) $\frac{1}{3}$.

The ironstone, which occurs both in nodules and thin bands, is too poor to be of any commercial value, although it has been tried at one or two places in the interior. There is also a good

deal of iron disseminated throughout the series, which gives rise to the blueish-grey colour generally prevalent; along certain lines this appears to become more oxidised, producing a red streaky appearance, which is well shown on the scars south of Scarborough.

The Grey Limestone where it first rises from the sea is a very insignificant bed, of not more than from 3 to 7 feet thick; but it rapidly thickens out towards the north and west, increasing to as much as 20 feet or more near Scarborough, to 70 feet at Cloughton, and to about 90 feet at Peak.

In Gristhorpe Bay this horizon is represented by a thin bed of shale and a little ironstone, which would be very difficult to trace across the low water scars if it were not for the bed of finely laminated sandstone below, which is beautifully interstratified with thin carbonaceous seams in quite a characteristic manner, and forms a well-marked reef throughout the length of the bay; at the western end of the bay these beds rise in the cliff, and there is obtained a much better view of them. They here have a thickness of 6 feet 10 inches, and consist of grey crumbly shale, crowded in the lower part with *Avicula braamburiensis*, *Ostrea flabelloides*, and other fossils, separated by two bands of hard impure ironstone nodules.

The following section was measured in the cliff:—

	Ft.	In.
Hard grey ironstone	0	10
Shale with fossils	1	6
Hard ironstone with fossils	0	6
Shale full of fossils	4	0
Total	6	10

This bed is seen again in the cliff and on the shore on the northern side of the point close to where it is cut by the great fault at Red Cliff, but the connexion between these two places is obscured by Drift.*

The thicknesses of the beds at this place are—

	Ft.	In.
Ironstone	1	0
Shale	1	6
Ironstone	0	4
Shale full of fossils	2	0
Ironstone	0	6
Black shale with sulphur	2	0
Total	7	4

Beyond the Red Cliff fault the Grey Limestone is next seen in Cayton Bay at Calf Allen rocks, where it forms the outermost

* Professor Phillips considered that the outcrop between these two places was concealed by the overlap of the beds above, but this appears very doubtful; it is more probable that the outcrop is concealed by Drift, and not that there is any real unconformity.

portion of the island that is exposed at low water and from which we obtained *Avicula braamburiensis*, *Myacites scarburgensis*, and a small *Lima*.

Between the faults at Osgodby Nab this rock again crops up, and is seen on the shore on the south side of the point, but it is so jammed or thrust in between the faults, and so mixed up with the Oxford Clay, Cornbrash, and other rocks which have apparently slipped over it, that its outcrop is very obscure, and it is difficult to make out how far it extends.

On the north side of the point in Carnelian Bay, close to the edge of the sands at low-water mark, there is a narrow ridge of these rocks exposed between the faults; the beds having a high dip to the south-west.

At White Nab the Grey Limestone Series again comes up above sea-level, and forms the whole of the scars nearly as far as the Spa at Scarborough, opposite to which it has a thin covering of sandstone; but a little further on it again appears being brought up by a sharp roll of the strata at the northern end of Ramsdale Scar in front of the Grand Hotel.

The beds at White Nab are harder and more ferruginous than those in Gristhorpe Bay, and contain *Gervillia acuta* in great abundance. The harder beds of rock from the shore at this place are occasionally used as a road material.

The following is the section of these beds at White Nab:—

Section of the Grey Limestone Series at White Nab.

	Ft.	In.
Massive sandstone with plant remains.		
Yellow sandstone with casts of fossils, principally *Avicula braamburiensis* - - - - - - -	1	0
Irony sandy beds with masses of shells, *Ostrea* (small), *Avicula braamburiensis*, *Trigonia signata* - - -	1	0
Grey shales with two ironstone bands and oolitic patches here and there, *Gervillia acuta*, *Av. braamburiensis*, *Myacites*, &c. - - - - - - -	2	0
Thick band of ironstone crowded with *Gervilla acuta* -	0	8
Grey sandy limestone, very hard, forming a prominent scar at White Nab but splits up nearer Scarborough into grey shales and ironstones. *Am. Blagdeni*, *Chemnitzia scarburgensis*, *Ostrea flabelloides*, *Av. braamburiensis*, &c. - -	4	0
Very hard massive limestone, lower part obscured by shingle - - - - - - 5	0–6	0
Hard sandy bed, forming a large spread - - -	1	3
Clay with *Avicula* - - - - - - -	0	6
Grey soft bed - - - - - - -	1	0
Hard irony bed - - - - - - -	1	0
Beds below generally covered by the water, said to be about	12	0
Total - - -	30	5

From this section it will be seen that these beds have increased, in a distance of two miles, from about 7 feet to nearly 30 feet; and continuing along the coast to the north we find the series steadily increases until the thickness becomes quite three times the amount of this.

North of Scarborough the Grey Limestone does not again appear above sea-level till we reach Cloughton Wyke, where one of the finest and most accessible sections of this series occurs.

Cliff Section, Hundale Point, Cloughton Wyke.

	Ft.	In.
Irregular bedded sandstone with carbonaceous matter at base.		
Ferruginous shale - - - - - - -	6	0
Ferruginous bands with fossils in lower part - -	4	0
Shale with great numbers of fossils: *Belemnites giganteus*, *Avicula braamburiensis*, *Avicula inæquivalvis*, *Gervillia acuta*, *Pecten clathratus*, *Astarte minima*, *Modiola imbricata*, *Myacites scarburgensis* - - - - -	27	0
Reef of grey shaly limestone with *Avicula braamburiensis*, *Ostrea flabelloides*, *Perna rugosa*, *Myacites calceiformis*, *Pentacrinus*, and *Serpula* - - - - - -	4	0
Second reef of shaly limestone - - - - -	2	0
Shale with *Belemnites giganteus*, *Avicula braamburiensis*, *Pecten lens*, *Pinna cuneata* - - - - - -	1	6
Third reef of shaly limestone - - - - - -	1	0
Shale with few fossils: *Avicula Münsteri*, *Cardium* - -	2	0
Fourth reef, hard limestone - - - - - -	1	0
Sandstone with fucoids: fossils in upper part - -	3	6
Hard siliceous sandstone forming a scar which runs out to sea - - - - - - - - - -	2	6
Shale with fossils - - - - - - -	1	0
Ironstone - - - - - - - -	0	6
Siliceous sandstone with ripple marks in two bands - -	2	0
Shaly sandstone with wavy lamination - - - -	2	0
Hard shale - - - - - - - -	2	0
Coaly shale - - - - - - - -	0	4
Ironstone band - - - - - - - -	1	4
Hard fossiliferous grey shaly limestone: *Gervillia acuta* very abundant - - - - - - - - -	4	0
Shale - - - - - - - - -	2	0
Black shale - - - - - - - -	2	0
Total - - -	71	2

Sandstone, forming Hundale Scar, 13 feet.

On comparing this section with that at White Nab it will be observed that a great thickness of shale has come in in the upper part; and this is where the chief difference appears to be; although, from the lower beds being hidden near Scarborough, it is not possible to determine what change occurs in the lower part of the section.

From Hundale Point the Grey Limestone Series may be seen in the upper part of the cliff, nearly as far as Hayburn Wyke; at which point it turns inland across Cloughton Moor, where it is cut by the Peak Fault.

To the north of the valley which comes down to Hayburn Wyke there is an outlying portion of this series, which is well seen in the Staintondale cliffs, and in the neighbourhood of Blea Wyke. In the latter place it appears to attain its greatest thickness on the coast, as will be seen from the following section, which was measured in the cliffs above the Point:—

Section at Blea Wyke.

	Ft.	In.
Flaggy sandstone with *Myacites* in great numbers along the lines of bedding: *Avicula braamburiensis* and a small *Pecten* abundant in the lower part; *Pholadomya Sæmanni?* occasionally found	15	0
Sandy shales, rather harder on top, with small ironstone nodules containing *Avicula braamburiensis*, becoming soft and calcareous in the middle, and harder and more calcareous towards the base; *Belemnites giganteus* occurs somewhat plentifully in this series	55	0
Calcareous sandstone which weathers into blocks with a rounded outline, the outer face often covered with stalactite; many small fossils	5	0
Band of flaggy limestone which weathers easily away: *Avicula braamburiensis, Pecten lens,* and *Gervillia acuta* very abundant	2	0
Hard calcareous shales with nodules of close-grained limestone almost composed of shells	10	0
Band of flaggy limestone having the appearance of hard calcareous mud	2	0
Thin flaggy sandstone with *Myacites* along the bedding planes, passing gradually to a sandy shale: casts of a small *Pecten* are very abundant near the base	15	0
Total	89	0

From the cliff section at Blea Wyke the outcrop of these beds again turns inland, and continues in a direction slightly north of west till it is cut by the Peak Fault a little east of Crag Hall. By this fault the beds are thrown up to the west, and their outcrop is very obsure for some distance. At Pye Rigg shales with *Avicula braamburiensis* are seen, which can be traced with more or less certainty along the sides of Helwath Beck to its junction with the Jugger Howe Beck below Dry Heads, where there is a splendid section of these measures.

Section in Bloody Beck, Harwood-dale.

	Ft.	In.
Massive sandstone.		
Hard ferruginous sandy shale	2	3
Hard ironstone band with *Avicula braamburiensis*	0	3
Quartzose gritty band	0	2
Grey sandy shale, getting harder at base	1	6
Calcareous band full of *Avicula braamburiensis*	0	4
Cherty band	1	0
Shale	0	7
Hard calcareous band	1	10
Dark argillaceous shale with large *Ostrea*	1	2
Quartzose gritty band crowded with *Avicula braamburiensis*, becoming sandy at bottom	2	2
Ironstone band	0	6
Shale with nodules and great numbers of species	15	0
Hard calcareous band with fossils	3	6
Hard limestone with well-marked joints, containing *Gervillia acuta*	1	0
Shaly limestone more calcareous in parts	5	0
Blue flinty bed	0	7
Flaggy ripple-marked cherty bed	0	5
Main flinty bed	1	4
Cherty sandstone with fossils	8	0
Total	46	7

*Across Howedale Moor the outcrop of these beds can be well traced by thin flaggy bands of sandstone containing casts of a small *Gryphæa*;† and near Cook House shales with *Avicula braamburiensis* are seen. The thin flaggy sandstones seem to be very persistent at the top of the Grey Limestone Series, and continue north and west at least as far as Kirk Moor Gate on Fylingdales Moor, where in the beck on the north-east side of the Scarborough road the following section may be seen:—

	Ft.	In.
Thin flaggy sandstone (capped with gravel). In one part of the stream it is slightly contorted - - - -	20	0
Dark coloured sandy ironstone-nodules with few fossils -	0	4
Dark micaceous shaly sandstone: a few plant remains -	0	10
Thin ironstone and sandstone with a few fossils - -	0	8
Band of ironstone, almost composed, in parts, of fossils: *Avicula braamburiensis, Trigonia recticosta*, a small *Chemnitzia*, &c. - - - - - - - -	0	6
Thin sandstone and shale with a few small fossils - -	2	0
Ferruginous shaly concretions with fossils - - -	0	7
Dark sandy shale with very small quartz pebbles - -	0	5
Ferruginous sandy nodules with a few small fossils - -	0	5
Dark shale with many casts of fossils - - -	0	4
Calcareous ironstone, very hard: *Avicula braamburiensis* very abundant - - - - - - - -	0	8
Shale, darker and less sandy, with one thin band of ironstone: *Avicula braamburiensis* scattered throughout -	4	0

The hard calcareous beds below are covered by Drift and débris, and therefore are not well seen in this section.

There is a repetition of part of the above section (in a little stream) about 200 yards to the north-east; and still further to the north-east, on the side of a small gully over Stevenson's Piece waterfall, there is a slight exposure of the upper part of the shales, while fragments of the calcareous beds have weathered out. From this point northwards the outcrop is rather uncertain, owing to a thin coating of Drift which covers the moor, and also to the fact that the hard quartzose grit, which is the usual representative of the Moor Grit, seems to be absent, and therefore there is no good feature to form a guide.

There is no positive evidence of this series across Fylingdales Moor; but that its outcrop has been proved in former times is probable from the name "Graystone" given to these hills, a name used in several places where beds of grey flaggy limestone have been dug out for liming the land.

The sandstone quarried at Soulsgrave is, from its lithological character, probably the Moor Grit, from which we can infer the outcrop of the bed below; while in the fields at the northern end of Ugglebarnby Moor small fragments of ironstone, with *Avicula braamburiensis*, have weathered out of the shale.

In making a shallow well at the new lodge at Newton House the lowest bands of shaly limestone were passed through, and the sinking was continued below to a seam of coal which was found at a depth of about 15 feet.

* The description of the northern part of the area is mostly from the account given by Mr. Barrow.

† Figured by Prof. Phillips, Geology of the Yorkshire Coast, 3rd Ed., Plate IX., Fig. 26.

At New May Beck Plantation a small quarry has been opened in the hard calcareous bands. The upper of these is about 4 feet thick, and of a bright blue colour in the interior; but the outer part soon loses its lime, and becomes a soft ferruginous sandstone, with a considerable number of casts of small fossils. The rock seems to decompose too readily to make a durable road-metal. The flaggy bed below is more sandy than at Peak; but it still contains much lime, and the usual fossils are very abundant in it

Some of the beds of limestone here appear to be very pure, as may be seen from the analysis given on page 471.

From this point till the beds sink beneath Blea Hill Beck the outcrop is very clear, and the following section may be seen :—

	FT.	IN.
Shales with small doggers of ironstone and fossils - -	15	0
Band of hard blue calcareous and ferruginous sandstone -	0	8
Sandy shale, slightly calcareous - - - - -	4	0
Calcareous sandstone, with a band of grit in the middle, almost composed of casts of *Avicula braamburiensis* -	2	6
Calcareous sandy shale or impure flaggy limestone - -	3	0
Hard limestone band full of shells in a crystalline condition	0	10
Hard calcareous shale - - - - - -	2	0
Flaggy sandy calcareous bed, harder in the centre - -	3	0
Blue calcareous sandy band - - - - - -	0	6
Calcareous sandstone, shaly in lower part, containing a few plant remains and small fossils - - -	7	0

The two calcareous sandy beds make fairly good road-metal, and the 10-inch limestone band will probably do the same. This latter is the only bed in the whole series that can fairly be called a limestone, the best of the other bands upon analysis yielding, according to information, only 34 per cent. of carbonate of lime.

The top of the series is not exposed in the bank, but there is probably not more than five feet of shale hidden by the débris of the Moor Grit; in the bed of the stream further south there is a flaggy sandstone with casts of *Myacites* in considerable numbers at the top of the shales. About 10 feet below the base of the series is a coal seam, said to average 11 inches thick; its outcrop can be seen, and there is a drift into it exactly under the spot where the above section was measured.

There are several other fine exposures of these beds in this neighbourhood, the western branch of the May Beck stream presenting a section several hundred yards long. The principal fossils here are *Avicula braamburiensis* in great profusion, *Gervillia acuta*, *Pecten lens*, a small *Trigonia*, *Ostrea*, apparently two species, and many *Belemnites*; but there is a remarkable paucity of species, except in the hard limestone band, from which, however, it is difficult to extract them.

For a short distance along the left bank of the stream the outcrop is marked by small masses of calcareous tufa, in which are some fine impressions of leaves of recent plants; but there is no absolute exposure till reaching Parsley Beck, where a good section of the lower hard calcareous beds may be seen. From this point the outcrop on Sleights Moor can only be fixed by the Moor Grit

above, and the small fragments of ferruginous sandstone or ironstone with *Avicula braamburiensis* that have been weathered out of the shales.

There is a small exposure of the lower hard beds of sandy impure limestone in Little Beck, not far from Goathland; but the rest of the series is completely obscured by fallen blocks of sandstone, &c. in the bed of the stream. At the base of the Moor Grit is the flaggy sandstone, containing casts of *Myacites* in great numbers. In Brocka Beck a nearly complete section can be seen, much resembling that at May Beck; but the beds as a whole are less calcareous, and much of the argillaceous matter is replaced by silica, so that the beds in the lower part of the series have become considerably harder, and are not nearly so fossiliferous as they were to the east.

In Eller Beck, near where the Whitby road crosses that stream, there is also a good section of the upper part of these beds, which seem to be rather more ferruginous at this spot. A short time since, a day-hole was put in close to the bridge, with the hope of working them for iron ore, but apparently without success. To the west of this the beds are seen rising in the railway cutting, where the Moor Grit and the calcareous shales below are well exposed, and may be traced along the edge of the moor by Killing Pits into Wheeldale Beck. A good deal of mystery hangs over these "pits" and various theories have been started to account for their origin, but there can be little doubt that they are ancient workings for this impure ironstone. Similar shallow pits occur at many other places on these moors, but always just over a thin ironstone; those to the south of Rosedale and at Dry Heads on Harwood-dale Moor being to this same bed. Bewick recognised that these pits were the remains of mining operations, but erroneously attributed the ore to the Kellaways Rock.*

Before proceeding further with the main outcrop it will be as well to take the large district which lies to the north. The Grey Limestone Series over the eastern part of this area more nearly resembles that we have been describing than that of the country to the west; in fact, it is the continuation of the north-east outcrop, from which it is only separated by the accident of denudation.

Over this district the outcrop of the Grey Limestone may be conveniently divided into three areas; first, the country round Whitby; second, the main portion of the Cleveland Hills; and, lastly, the isolated outlier of Eston.

The Series consists of three parts, of different lithological character which is more marked than it is to the south-east. The upper portion is mostly shales containing ferruginous nodules which become more calcareous lower down; these rest on beds of sandy marl with thin calcareous sandstones which towards the west pass into hard coarse grits; while at the base is a varying thickness of impure limestone bands.

* "Geological Treatise on the District of Cleveland," p. 77, 1861.

Near Whitby there are several exposures. Commencing with the eastern part of the large mass south of the Esk, which is roughly cut in half by the Whitby fault, we find at the southern end the following clear section exposed in Gate Holm Beck just where the lane to Hawsker Bottoms crosses that stream.

	Ft.	In.
Dark grey shale - - - - - - -	2	6
Band of ironstone doggers with fossils - - -	0	6
Dark shales - - - - - - - -	2	6
Ironstone band, with *Avicula braamburiensis*, *Pecten lens*, *Gervillia acuta*, *Cucullæa cancellata*, *Astarte minima*, a large *Trigonia*, and several other fossils - - -	0	10
Calcareous sandstone in cubical blocks containing many small fossils - - - - - - -	5	0
Flaggy impure limestone containing a few species in great abundance - - - - - - -	3	0
Sandy calcareous shales - - - - - -	5	0
Hard dark calcareous shale with nodules of limestone almost composed of shells in a semi-crystalline condition - -	3	0
Impure flaggy limestone very fossiliferous - - -	3	0
Dark shale with a few fossils - - - - -	2	0
Total - - -	27	4

Below the last band of flaggy limestone there is a fall of about 15 feet, the beds beneath consisting of dark shales and thin sandstones. This is an exceedingly convenient section to examine, as the limestone beds were formerly quarried and burnt for lime, the flaggy bands being also used as paving for footways. Many blocks with *Pecten lens, Avicula braamburiensis*, &c. may now be seen in the paved footway from Whitby to Robin Hood's Bay.

The upper flaggy limestone band continues in the bed of the stream for some distance to the south, while the shale may be occasionally seen in the banks; proceeding northwards the hard calcareous beds crop out in several places along the sides of the next small stream near Nype Howe, but beyond this, till we reach Moorgate Lathes, the position of the Series can only be inferred from that of the hard white Moor Grit above. Here the upper part of the hard calcareous bands and the shales over them may be seen. The Moor Grit crops out further up the stream, the lower part of it being a flaggy sandstone. In the main branch of Spittle Beck, at the waterfall not far from the Lodge, there is a complete section.

	Ft.	In.
Close grained sandstone, evenly bedded and flaggy at base -	20	0
Softer flaggy sandstone, with casts of a *Myacites* - -	6	0
Band of ironstone nodules, small specimens of *Avicula braamburiensis* - - - - - - -	0	4
Soft sandstone, splitting to very thin layers - - -	3	0
Ferruginous sandy shale, slightly calcareous in lower part, with calcareous nodular band at base - - -	3	0
Shaly limestone or marl, a mass of shells, *Avicula braamburiensis*, *Gervillia acuta*, and *Pecten lens*, &c. - -	3	0
Hard blue siliceous limestone - - - - -	1	6
Calcareous shale - - - - - - -	5	0
Shaly limestone or marl - - - - - -	1	10
Hard sandy calcareous shale - - - - - -	4	0
Impure limestone band - - - - - -	2	0

Below this are dark shales with several trial-holes for soft jet, all of which appear to have been unsuccessful.

The shaly limestone bands are more of the nature of a fossiliferous mudstone with great numbers of *Aviculæ*, which, when first exposed, is very hard and difficult to break, but rapidly disintegrates from loss of lime, and can then be broken to pieces with the fingers.

From this point the outcrop under the Drift soon comes against the Whitby fault, and is thrown down to the west, reappearing in the banks of the Esk. It is first seen again at the borehole put down in Larpool Wood, opposite the Gas Works, but as the excavation here is now full of water, it is impossible to get any account of the strata passed through, nor does any record of the section appear to have been kept. A little further south under the chalybeate spring there is a small square hole sunk, from the sides and bottom of which ironstone nodules with *Avicula braamburiensis* may be found. The top of the shale keeps just above flood-level till we reach Cock Mill, in Larpool Wood, where the waterfall passes over the Moor Grit, and cuts into the soft shales of the Grey Limestone below. Some distance to the south-west there is an interesting series of sections, in Shawm-Rigg Beck, and its tributaries towards Sneaton. Although the entire series may be seen three or four times over, the vegetation is too dense for a detailed section to be measured, but the following is an approximately accurate summary :—

	Ft.	In.
Light coloured sandy shales with thin bands of sandstone, containing a few casts of fossils; at the base is a row of ferruginous nodules crowded with *Avicula braamburiensis* -	10	0
Hard calcareous sandstone with bright blue-grey fracture; top often covered with fragments of crinoid stems -	4	0
Flaggy siliceous limestone band; *Gervillia acuta* abundant; also *Pecten lens* - - - - - - -	1	6
Calcareous shale, about - - - - - -	5	0
Very hard calcareous beds, lower part has a conchoidal fracture - - - - - - - -	2	0

The outcrop to the south of this can only be inferred, the sole evidence of its presence being the flagstone quarries in the Moor Grit in and around Sneaton.

North of the Esk there are a few sections which show the position of the Grey Limestone, the principal of these is in the bank opposite the iron foundry between Whitby and Ruswarp, where shales with small fossils can be seen; the sandstone above, which is exposed in the railway cutting, is evidently the Moor Grit. About a quarter of a mile north-west of Ruswarp, in a little stream running east and west, there is a continous section for some 200 yards of the shale and upper part of the calcareous beds. The latter are remarkable for the abundance of a large *Ostrea* in them. A very small section of siliceous calcareous rock is also seen in the small stream below Sneaton Castle.

The next area to be considered is the great central portion of the northern plateau of Cleveland, around which the Grey Lime-

stone series forms a thin belt, somewhat broken by faults. The east end of the outcrop is inferred from that of the Moor Grit, the only exposure of the beds below being at Barnby Tofts,* where the shales with *Avicula braamburiensis* are seen. Its course is interrupted by the fault seen in the cliff at Runswick, which throws the beds down some 50 feet to the west. In the deep dale just north of Mickleby the Moor Grit has been quarried, and this bed continues to be the only clue to the position of the Grey Limestone Series till its base is seen in the Newton Sandstone Quarries, at the head of Borrowby Dale. Here resting on the sandstone is some carbonaceous shale with soft jet, above which is a small exposure of calcareous sandstone, evidently the base of the Grey Limestone Series. For some distance to the north and west the outcrop can only be inferred from the grit beds above.

At Rousby Mill there is an exposure of Moor Grit and part of these beds, the section being as follows:—

	Ft.	In.
White gannister-like sandstone with plant remains	12	0
Sandy shale with bands of thin sandstone	7	0
Ironstone band, a few small fossils	0	6
Grey sandy shale	0	10
Ironstone band, many fossils	0	6
Shale	6	0
Gritty ferruginous band full of *Avicula braamburiensis*	0	3
Base of waterfall.		

The calcareous beds are seen at intervals further down the stream, and again to the east in Bitch Hill Beck.

The outcrop now trends south-west, evidently flanking an old line of valley, being completely concealed by Boulder Clay as far as Scaling, where the following beds are exposed:—

	Ft.	In.
Sandy ferruginous shale, nodules in upper part containing *Avicula braamburiensis*, *Pecten lens*, *Gervillia acuta*, *Astarte minima*, and a few other small fossils	15	0
Calcareous hard sandstone with fossils in upper part	3	0
Hard sandy calcareous shale	2	6
Bands of calcareous fine-grained sandstone	8	0
Total	28	6

The second bed represents the fossiliferous grit that is so strongly developed to the south and west, while the long slab-like beds at the base represent the marl or limestone beds nearer Whitby.

Beyond Scaling, a few small sections are seen in the gullies under Grinkle Park, beyond which the Moor Grit, which is well devoloped here, is the only clue to the outcrop.

Two of the borings put down by the North Loftus Iron Co. must have passed through these beds, but there is no mention of them. After an obscure course for several miles, a section is

* Misspelt Lofts on One-inch Map.

met with in the small stream some 300 yards north of Handale Abbey, which is as follows:—

	Ft.	In.
Earthy ironstone nodules, *Avicula braamburiensis*, *Astarte minima*, &c. - - - - - - -	1	0
Shale, ferruginous and calcareous - - - -	5	0
Thin sandstone with lines of sandy ironstone - -	2	0
Calcareous and ferruginous sandstone, very hard - -	1	6

Thick Drift, again, obscures the ground to the south and west, and the outcrop can only be approximately traced for some distance.

In the small outlier on which Liverton Lodge stands, fossiliferous grit crops out at the top of the bank above Rosecross Wood, the Moor Grit being also exposed about the Lodge, but the southern portion is again covered by Drift.

Along the banks of Kilton Beck, the Moor Grit, with the Grey Limestone below, is clear of Boulder Clay for a considerable distance, the former rock often forming a bold crag. Petrifying springs indicate the presence of calcareous beds, which may be seen below the fossiliferous sandstone at Cabin Hole Quarry. At Scabdale Bower, near Liverton Mill, the following section was measured:—

	Ft.	In.
Sandstone (Moor Grit) - - - - - -	40	0
Sandy shale with hard bands - - - - -	5	0
Ferruginous band - - - - - - -	0	2
Shale - - - - - - - - -	6	0
Ferruginous bands, fossils - - - - -	0	3
Grey shale - - - - - - -	7	0
Fossiliferous, calcareous sandstone - - - -	10	0

South of this point the ground is entirely clay-covered, the Moor Grit cropping out only in the bed of the stream in Alder Wood; while a little north of this below Elm Heads the calcareous base of the Grey Limestone is seen.

The next evidence is at Pissing Scar in Dale Beck, where the same beds crop out. In the other branch of this stream in Kate Ridding Wood, opposite this section, the whole of the lower part of the Grey Limestone is exposed, and some well-preserved fossils may be obtained, the beds having been quarried to a small extent for road-metal. A large fault cuts off the outcrop a little west of these two sections.

Some distance to the north-east the base of the series is visible in Goat Scar Wood, the next clue to the outcrop being the Moor Grit at Kilton. At Crags Hill, near Crags Hall, the fossiliferous grit makes a considerable spread, the same bed coming to the surface a little south of Brotton village. In the railway cutting just south of Brotton Station the following beds are laid bare:—

	Ft.	In.
Hard white sandstone - - - - - -	30	0
Sandy shale - - - - - - - -	10	0
Ferruginous nodules resting on ferruginous grit, with casts of *Avicula*, *Gervillia*, *Pecten*, &c., passing down into a calcareous bed.		

The new pit put down by Messrs. Bell Brothers commences just above the Grey Limestone, the Moor Grit having been quarried away. In the little stream just west of North Skelton shaft, the following may be seen:—

	Ft.	In.
Hard calcareous and fossiliferous grit	5	0
Softer and more sandy beds	5	0
Argillaceous shales (Estuarine beds).		

In the shaft, and again in the water-level, the Moor Grit and Grey Limestone were cut through, but no record of their nature and thickness was kept. For nearly two miles neither of these beds have a clear outcrop; but a good clue is obtained from No. 3 of the North Skelton borings, which pierced both.

On the south bank of Bushy Dale, near Stanghow Ridge, the fossiliferous grit crops out, and is clearly seen abutting against the Moor Grit. There must consequently be a small break in the outcrop here. The ridge itself is formed of the Moor Grit, and as Jenny Frisk Sandstone Quarry is below the Grey Limestone, the outcrop of the latter must be in the bank between the two.

The outcrop here splits into three parts. The first turns round to the east and ends against a fault, its exact position being obscured by clay. The second passes round the head of the dale formed by Lockwood Beck, its course being hidden by sand and gravel till it reaches the fault already referred to, by which it is cut off. The third and main portion of the outcrop continues for some distance under Boulder Clay till Woodhill Gill Quarry is reached, where the sharply defined base of the grit above fixes exactly the position of the Grey Limestone, the water also showing the presence of calcareous beds.

In Tidkinhow Slack the following section was measured:—

	Ft.	In.
Flaggy grit	—	
Sandy shale	15	0
Fossiliferous grit	2	3
Hard blue limestone	0	6
Blue shaly limestone	5	0
Siliceous crystalline limestone	0	6
Ferruginous and calcareous sandstone	5	0

The fossiliferous grit makes a considerable spread on the ridge dividing Sleddale from Commondale, and great blocks of the same bed mark the outcrop on the west flank of the hill. Another similar spread forms the tabular hill on Commondale Moor, and also on the outlier of Kempswithen between here and Basedale. This grit is very hard and well developed in this neighbourhood, and makes a well-marked feature in the structure of the district.

Skirting round Raven Gill, above Skelderskew, the Grey Limestone may be traced either by the Moor Grit above or occasionally by the fossiliferous grit. Further east, just above Cobble Hall, is an old quarry, from which the calcareous beds were once obtained and burnt, but the limestone is very impure, and as it was found difficult to prevent the whole running to a slag, the working of it was discontinued. The section is too

obscure to be given in detail. The base of the Moor Grit is at the top of the quarry; below this comes the shale with nodules, the calcareous bands being at the bottom. Just beyond this, a fault throws the limestone down to the east, but its position is still clear enough for some distance, although the outcrop above Castleton Station is broken by two small faults. In Haw Ridge Slack, bands of flaggy limestone crop out in the small stream, the Moor Grit, which is finely developed, forming a clear upper boundary both here and round Ewe Crag in the adjoining small valley. Just under Lop Hall a fault is seen, passing through the basement beds of the limestone, and throwing them down some 30 feet. The little gully that this fault crosses gives the following section:—

	Ft.	In.
Soft calcareous sandstone with *Pentacrinites* - -	2	0
Sandy ferruginous shale - - - - -	4	0
Hard siliceous and ferruginous sandstone with *Gryphæa*, &c. - - - - - - - -	8	0

Estuarine sandstone below.*

It is impossible to obtain a complete section of the Grey Limestone Series here, but in Clither Beck, to the north-east, the beds above may be seen. These are more fossiliferous, as well as sandy and ferruginous, but only slightly calcareous, the lime having evidently been to a large extent dissolved out.

South of Danby Beacon the shale with nodules and the fossiliferous grit are seen at intervals as far as Wall Corner. The various coal pits here show very clearly what a large portion of the calcareous beds are completely dissolved away at the outcrop; for in one of these shafts strong beds of calcareous sandstone and impure limestone are seen, having a thickness of from 15 to 20 feet.

On the west side of Stonegate Gill the fossiliferous grit caps the great scar almost along its whole length; it crops out in the road down to the Mill, and can be followed, as well as the shale above, till they are cut out, or rather thrown down, by a considerable east and west fault.

On the opposite side of this valley there is a long outcrop of these beds, which are seen in a few of the small gullies between here and Egton, and their position may be fixed by the Moor Grit above. On the north side of Egton Low Moor they are entirely hidden by clay, the flaggy part of the Moor Grit near Fishburns Plantation being the only clue to its position. There are small outcrops of this Series in Birk Head Beck and the higher part of Mickle Beck; the principal evidence for which is afforded by the sandstone above.

The third and last area of the Cleveland district is the roughly elliptical outcrop of the Grey Limestone Series on Eston Hill. This is much faulted, the breaks being clearly shown by the fossiliferous grit, which is here strongly developed, and is coarser than in any other portion of its outcrop, the grains of quartz

* For continuation of this section, see page 225.

being often as big as peas. It is also characterised by the abundance of casts of crinoid stems. These features may be well seen on Normanby Moor, and also to the south-east of Upsall Shaft. It is very doubtful if any limestone exists below this grit, as no mention of it is made in the boring on Barnaby Moor, which must have passed through it.

Returning again to the main outcrop west of Goathland the Grey Limestone Series may be easily traced beneath the great scars on either side of the beck south of Hunt House, and thence, skirting along the southern edge of Wheeldale Gill, crosses that stream near its upper end and divides into two portions, one of which spreads out in a large area over Egton High Moor to the north; the other turns south and follows the escarpment on the east side of Hartoft Beck to Spires Bank, where, owing to the strong southerly dip, the beds plunge down into the stream in a very short distance.

In the banks of the river Seven the beds although seen afford no continuous section, and rising rapidly on the further side of the stream pass by the old "Smelting Works," where again this ironstone seems to have been worked in ancient times. On Spaunton Moor owing to the steep dip the outcrop of the Grey Limestone runs up into a series of points or nabs between the numerous streams coming down off the moor. In a quarry on one of these nabs at Spindle Thorn there are about 12 feet of shale over 5 feet of dense hard blue silicious limestone; this limestone, which is quarried for road-metal, has rather a peculiar appearance and when freshly broken by the roadside might, from its dark colour and dense structure, be easily mistaken for whinstone. In some places the limestone decomposes rather readily, especially along lines of joint, so that usually when seen in section the rock has more the appearance of a line of large boulders than a continuous bed; from this cause the outcrop is often difficult to follow, as what may be good strong rock at one place is often mere clayey sand a little further on. About Spindle Thorn, however, a strong fossiliferous grit begins to come in below the limestone, which forms a good spread on the moors, and allows the outcrop to be traced without difficulty further west.

Most of the small becks which cross the outcrop afford good exposures of these beds, especially a small ditch called "The Gulf" on the east side, and Harland Beck on the west side of Farndale; the first of these shows the hard blue limestone resting on calcareous sandstone very fossiliferous, the whole capped by about 20 feet of shale.

West of Farndale a thick fossiliferous grit appears in the upper part of the Grey Limestone Series and forms great spreads often more than a square mile in extent, capping the ridges and watersheds between the various dales. This causes a great change in the character of the country; for where these great spreads of fossiliferous grit occur, long, flat, dip slopes are seen, which are usually very dry, except where covered by peat, and the wet Estuarine clays have a much narrower outcrop; but

further east, where this grit is absent, a large area is formed of low rounded hills of the higher Estuarine strata, with simply a belt of the Grey Limestone Series beneath; the country being bleak and wet in the extreme. About Swinacle this grit makes a small spread before descending to Rudland Beck, where the limestone is seen beneath, and the beds may be followed down this beck to its junction with the Hodge Beck at Pennyholme Wath. A few yards further up the main stream is a small gill, at the bottom of which the limestone beds are exposed. From this point the outcrop of the grit passes just along the top of Mitchell Hagg Wood to the ordnance station, 1,072, at Lambfold Hill, on the west side of Bransdale, the bed being close to the surface, and almost bare for a considerable distance.

In Bonfield Gill, at the low end near Throstle Nest, the grit with crinoids is exposed under the footbridge. Bogmire Gill is encircled by the outcrop of these beds; and, where they approach the stream at the south end of the valley, several good sections are seen, the best being in a gully just below the road at the end of the most southerly intake. Here may be seen some 20 feet or more of shales, then a few feet of hard, blue limestone; below which comes the fossiliferous grit about 10 feet thick, and then the blue limestone at the base, the exact thickness of which cannot be seen. A little further south these limestone bands form the bed of the stream for nearly 50 yards and can be well examined. They are, however, not so fossiliferous here as they are further east.

There is an inlier of the Grey Limestone Series at Snaper House, this little valley being almost composed of these beds. The blue, flinty limestone, which must be at least 10 feet thick, and is much used locally for road-metal, is exposed just below the junction of the two branches of the stream. On the moors to the north these beds make a great spread, running up as far as the ordnance station 1197, where an old limekiln may be seen which was erected to burn the flaggy limestone that occurs below the grit, and is unusually well developed in this area and to the west of Bilsdale. Generally the quantity of water percolating through the porous grit is so great that this limestone is mostly dissolved away at the outcrop. On the western side of this outcrop there are two small faults, one of which cuts out the limestone for some distance.

At Carr Cote the Grey Limestone makes a small spread, and, passing round below Rosy Dike where there is a section, dips rapidly into Bilsdale. The outcrop is very clear all about here and the Series is well exposed where it crosses the main road a quarter of a mile south of Laskill. Just south of this they enter the river and form a fine scar below Grimes Holme.

On the moors to the north there are several outliers of the Grey Limestone Series, the one to the north of Rosedale being of considerable size. These are not of particular interest; they form barren moorlands, generally composed of the dry porous

fossiliferous grit, but frequently covered by peat, which completely alters the character of the ground.

On the west side of Bilsdale the outcrop follows the edge of the moor, where the three divisions of shale, grit, and calcareous beds are very distinct, and can be followed for some distance. The total thickness of these beds is about 70 feet, but there is no clear section in which the whole of the series can be measured. Below Novey House on the west side of Ladhill Beck there is the following section, but only the calcareous bands at the base are clear :—

	Ft.	In.
Sandstone of the Moor Grit.		
Shales with fossils - - - - - - -	—	
Coarse porous grit with casts of *Avicula braamburiensis* and other fossils - - - - - - -	—	
Hard, sandy, siliceous beds - - - - -	3	0
Sandy shales - - - - - - -	5	0
Siliceous and calcareous beds - - - -	4	0
Shales - - - - - - - -	—	
Estuarine sandstone.		

There is a considerable thickness of the porous grit in the upper part, which being harder than the rest of the series forms a prominent feature over these moorlands. The blue flaggy limestone at the base of the series in which *Gervillia acuta* and *Avicula braamburiensis* are very abundant, also sometimes makes a clear outcrop, this limestone being well developed here as it is on the opposite side of Bilsdale. It is well seen in the road at the side of the enclosures above Wether Cote, and forms a large spread on the moor to the north, completely encircling the higher part of Ladhill Beck, so that the Estuarine beds exposed in this valley form an inlier.

On these moors the limestone has been worked and burnt for lime at one or two places. Near Hazel House there are some curious hollows called "Hell Holes," which have evidently been formed in the grit by the calcareous beds below being dissolved out.

Both in Ladhill Beck and the River Rye the Grey Limestone Series is well exposed, and west of the latter forms a good feature, which may be easily traced by Brewster Hill and Gate Cote to Dale Head, where it turns round the head of valley by Stephen Thwaites and Newfield House. At this last place the calcareous beds were worked for lime or cement, and some time ago in pulling down an old wall cemented with this lime, the bricks had to be broken to pieces before the lime showed any signs of giving way. North of this these beds cross the higher waters of the Rye and may be traced across the moors to the ordnance station 1,184 on Whorlton Moor. The outcrop now turns round to the west, and although broken by several small faults forms a considerable spread on these moors.

On Osmotherley Moor, near Low Mossy Grain, the fossiliferous grit, which contains casts of *Pentacrinites* in great numbers, makes a series of little steps up the hill side. Just below a drift was put

in to the limestone, the bottom bed of which is only a foot thick and full of *Gervillia* and *Pecten*. At the head of Oak Dale, near Moor House, where the rock is quarried and partly mined for road-metal, a drift has also been made into the basement limestone, which is here about 6 feet thick, very hard, and of a blue colour.

It is quite evident from the above that going north the calcareous beds almost disappear in this area, and at the same time that the grit becomes thicker and coarser. This last fact is well brought out by the great detached mass of fossiliferous grit on the watershed between Scugdale and Raisdale; which is at least 40 feet thick, and contains quartz grains of the size of a pea, this and the grit on the outlier at Eston being by far the coarsest form in which this bed is known. These grits are very porous, and from their base give out powerful springs, some fine examples of which may be seen at the sources of the Cod Beck above Osmotherley, and again at Newfield House on Snilesworth Moor.

The Grey Limestone follows the brow of the hill for some distance along these moors running out in a broad tongue above Over Silton, where the limestone beds at the base have been worked. In Swinestone Cliff the three divisions become very distinct, and the fossiliferous grit, which is very ferruginous in its upper part, forms a bold crag in the plantation below the house.

In the neighbourhood of Kepwick the Grey Limestone forms the conspicuous promontories above Nab House and above Atlay Bank, being well exposed at these places, and also where the road crosses the outcrop east of the village at Rag Robin Turn. Above Cowesby Wood these beds follow the brow of the hill for some distance, and at Brockholes, near Kirby Knowle, where a large landslip has taken place,* the following section was measured:—

Section at Brockholes, Kirkby Knowle.

		Ft.	In.
	Grit, with a siliceous fossiliferous bed near the centre	16	0
	Shales passing up into sandstone	4	0
	Rubbly calcareous beds full of fossils	5	0
	Siliceous sandstone with fossils (*Ostrea*)	8	0
	Argillaceous limestone	0	6
	Sandstone	0	6
	Hard bluish grey limestone	1	0
Estuarine Beds.	Shales.		
	Massive sandstone.		
	Shales.		
	Massive sandstone, with shales and a little jet in the centre.		

East of Kirkby Knowle the Grey Limestone winds round the hill forming the two projecting nabs above Westow Hall and Boltby; and, turning up the valley of the Lunshaw Beck, is exposed in the bed of that stream for nearly a mile. Below Lunshaw House there are some trial-holes into the lower part of the limestone, but for whatever purpose these were made, it seems to have been a failure.

* This landslip occurred about the year 1800. See Young and Bird, Geol. of Yorksh., p. 82.

On the east side of Lunshaw Beck the outcrop is entirely hidden for some distance by large landslips of Calcareous Grit and other rocks which have come down from above, and it is only on the projecting points, as below Hesketh Grange, Little Moor, and near Garbutt Wood that we get sections in the rock.

South of Whitestone Cliff the outcrop is again hidden for some considerable distance, and it is not until the beds turn round to the east below Roulston Scar that they are again exposed. The Grey Limestone now becomes more easy to trace, and may be followed along the hillside to Snever Wood, where it forms a conspicuous bank in the lower part of that wood. The outcrop here crosses the beck, and after a somewhat obscure course round the hill to the west of Oldstead, is again well exposed in the neighbourhood of Oldstead Grange, where it makes the low feature on the east side of the old fish pond. At the southern end of this pond the Grey Limestone meets the large east and west fault of the Coxwold valley, and is thrown down some hundreds of feet, the outcrop being shifted nearly four miles to the west.

Between Byland Abbey and Ampleforth there is an inlying outcrop of these beds which skirts round the hill at the back of Wass village; the bed is only exposed at the corner of Burtis and Carr House Wood, just east of which it again meets the large fault.

Over the north-west moorlands and at the southern end of the western escarpment there are several outliers of the Grey Limestone Series. The most northerly of these is the patch of fossiliferous grit on Whorlton Moor where the beds are depressed by an east and west fault, and form a line of crags on the south side. The rock here, as we noticed above, is much coarser than anywhere else in the district. In the north-west corner of the Moors there are also some small patches of this rock which are much intersected by small faults, and to which, to a great extent, they owe their preservation.

Further south on Snilesworth Moor there are four of these outliers between the several branches of the Rye which, from the strong character of the grit and the absence of Drift, are very distinct.

At the south end of the great escarpment, there are two outliers of the Grey Limestone Series; one of these occurs on Hood Hill near Kilburn, the other on the hill behind that village. At the last of these places the outcrop is rather obscure, but a small portion of the limestone is seen on the northern side of the hill; at the south end the Grey Limestone is thrown out by a fault, so that the limestone which is there seen apparently on the same line of strike really belongs to the Millepore Bed.

On the southern side of the north Coxwold fault the Grey Limestone is first seen at Thirkleby Barf, where it has been extensively quarried for road-metal. The beds here, which are harder and more massive than is usually the case, are divisible into two portions, the lower part consisting of hard beds of blue

fossiliferous limestone, while above this are soft massive sandstones with casts of fossils, which become more flaggy in the upper part. These beds, which at Thirkleby Barf dip about 15 degrees to the north-east, to the east of Burtree House curve round, and above Barf Hill dip at about the same angle slightly to the west of north, so that the outcrop is extended in an easterly direction by Wildon Hill to Coxwold; at all of these places the rock is exposed in old quarries, but is not seen along the intermediate ground, probably owing to the thick covering of Boulder Clay lying in the hollows between. In the beck to the south of the railway at Coxwold these beds are seen dipping to the south-east at an angle of 10 degrees, being bent over towards the second large fault by which they are thrown up so as to crop out only as outliers at The Mount and Park House in Newburgh Park.

In the Howardian Hills the Grey Limestone Series is much more flaggy than it is over the northern region and, having been quarried for a great number of years at Brandsby as a material for mending roads, is better known in this district as the "Brandsby Roadstone."

It is a hard siliceous limestone splitting up into large slabs, in fact some of the beds are so fissile as to afford roofing slates, for which purpose it was largely used in former years; the upper portion of the rock is a brown porous grit, very full of casts of *Avicula braamburiensis*. It is very frequently only this upper grit which is exposed, the limestone below being decomposed into soft sand, and not making any feature. The total thickness of these beds is probably about 40 feet, but of this there will not be more than about 20 feet belonging to the limestone.

The largest spread of this rock is on the summit of the hill about Yearsley, where it occupies nearly all the high ground between Newburgh Park and Brandsby; it also forms the outliers mentioned before in the higher part of Newburgh Park and at Park House; after this it is much broken up by faults into several isolated patches, which are seen near Redcar House below Gilling Park, between the faults north of Grimston Moor, at Hovingham Lodge, and at the foot of the Middle Oolite escarpment across Slingsby Moor. The outcrop is also repeated at Wiganthorpe and in the low ground north of Terrington by the great east and west fault north of those places.

East of this the outcrop is cut out for some distance by the faults near Castle Howard, but is repeated again on Welburn Moor where it forms a considerable spread although there is no good section of the rock. It appears again in Pretty Wood and crossing Cram Beck passes by rather an obscure course across Hutton Hill to the large fault at the York and Malton road; here it abuts against the Calcareous Grit forming Hutton Banks, the effect of the fault being very clear and distinct. The soft sandy rock has been excavated at this point and contains large calciferous doggers crowded with *Avicula braamburiensis* and other fossils. By this fault it is thrown down, and forms the outcrop in Stonecliffe Wood, and also on the other side of the river in Firby

Wood. At the former of these places the rock has been quarried to build the railway wall just below, and affords one of the best section of the series in this neighbourhood; there is here exposed a considerable thickness of soft sands with two or more bands of hard siliceous rock very full of fossils, *Ostrea, Avicula, Gervillia, Astarte,* and *Myacites* being particularly abundant. Mr. Hudleston gives the following list of fossils from Stonecliffe Wood.*

Terebratula maxillata ?.	Astarte, sp.
Avicula braamburiensis (? two varieties).	Cucullæa, sp.
Gervillia acuta (two varieties).	Myacites decurtatus (one specimen).
Ostrea flabelloides.	—— securiformis (very plentiful).
Pecten lens.	Mytilus sublævis.
Perna rugosa.	Pholadomya (like P. angustata).
Pinna (a large form).	Trigonia signata.
Placunopsis, sp.	

South of Firby Wood the outcrop is shifted further to the east by another fault, and, making a somewhat large spread around Westow Church, is again seen in the road beyond Eddlethorpe, where it forms a good feature. South of this there is a small indistinct outcrop between the faults east of Jenny Milner Grange beyond which we have not been able to follow it. About Burythorpe, where these beds should come out again, there is not a trace of any fossiliferous rock at this horizon.

The Grey Limestone of the Yorkshire area was for a long time considered the equivalent of the Great Oolite of the South of England; but, if the list of fossils given below be compared with that obtained from the Great Oolite of the southern counties, the difference is at once apparent. In fact, if we exclude those forms which have a wider range, there are very few species common to the two.

Fossils from the Grey Limestone.

ECHINODERMATA.

Pseudodiadema depressum, *Ag.*	Astropecten scarburgensis, *Wr.*
—— vagans, *Phil.*	Ophiolepis Leckenbyi, *Wr.*
Rhabdocidaris maxima, *Münst.*	—— Murravii, *Forbes.*
Astropecten Leckenbyi, *Wr.*	Pentacrinus vulgaris, *Schlot.*

ANNELIDA.

Serpula intestinalis, *Phil.*	Serpula tetragona, *Sow.*
—— lacerata, *Phil.*	Vermicularia nodus, *Phil.*
—— plicatilis, *Goldf.*	Vermilia sulcata, *Sow.*
—— squamosa, *Phil.*	

CRUSTACEA.

Pseudoglyphæa Etalloni, *Oppel.*

BRACHIOPODA.†

Rhynchonella subtetrahedra, *Dav.*	Terebratula submaxillata, *Dav.*

* Proc. Geol. Assoc., vol. iii., p. 331, 1874.

† *Terebratula intermedia*, Sow. is given by Prof. Phillips from the "G. O. Westow, Whitwell, Cloughton, Swainby." It is probable however that the Millepore Oolite is intended, although that formation does not occur at Swainby. It is very doubtful if either *T. intermedia* or *T. globata*, as also stated by Phillips, occur in the Grey Limestone, in which Brachiopoda are very rare.

LAMELLIBRANCHIATA.

Avicula braamburiensis, *Phil.*
—— echinata, *Sow.*
—— inæquivalvis, *Sow.*
—— Münsteri, *Goldf.*
—— ornata, *Goldf.*
Gervillia acuta, *Sow.*
Gryphæa gigantea, *Sow.*
Lima cardiiformis, *Sow.*
—— duplicata, *Sow.*
—— educta ?, *Whidb.*
—— pectiniformis, *Schlot.*
—— punctata, *Sow.*
Ostrea flabelloides, *Lam.* (O. Marshii, *Sow.*).
Pecten clathratus, *Röm.*
—— demissus, *Phil.*
—— lens, *Sow.*
—— paradoxus, *Goldf.*
—— saturnus, *d'Orb.*
Perna mytiloides, *Lam.*
—— rugosa, *Goldf.* (P. quadrata, *Phil.*).
Pinna cancellata, *Bean.*
—— cuneata, *Bean.*
Placunopsis inæqualis, *Phil.*
Pteroperna plana, *L. & M.*
Arca Eudesii, *L. & M.*
Astarte elegans, *Sow.*
—— minima, *Phil.*
—— recondita, *Phil.*
Cardium cognatum, *Phil.*
—— semiglabrum, *Phil.*
Cucullæa cancellata, *Phil.*
—— cylindrica, *Phil.*
—— imperialis, *Bean.*
—— reticulata, *Bean.*
Cytherea (Cyprina ?) dolabra, *Phil.*
Goniomya v-scripta, *Sow.*
Gresslya peregrina, *Phil.*
Homomya crassiuscula, *L. & M.*
—— gibbosa, *Sow.*
Isocardia cordata, *Buck.*
—— nitida, *Phil.*
Leda anglica, *d'Orb* (Nucula lachryma, *Phil.* non *Sow.*).
Lucina despecta, *Phil.*
Modiola cuneata, *Sow.*
—— gibbosa, *Sow.*
—— imbricata, *Sow.*
—— Leckenbyi, *L. & M.*
—— Lycetti, *Morris.*
—— ungulata, *Phil.* (M. tumidus, *Y. & B.*).
Myacites æquatus, *Phil.*
—— Beanii, *L. & M.*
—— calceiformis ?, *Phil.**
—— decurtatus, *Phil.*
—— Goldfussii, *Lyc.*
—— scarburgensis, *L & M.*
—— securiformis, *Phil.*
Mytilus sublævis, *Sow.*
Nucula variabilis, *Sow.*
Pholadomya acuticosta, *Sow.*
—— angustata ?, *Sow.*
—— Heraulti, *Ag.*
—— ovalis, *Sow.* (Ph. nana, *Phil.*).
—— Sæmanni, *L. & M.*
Pholas pulchralis, *Bean.*
Quenstedtia lævigata, *Phil.*
Sowerbya triangularis, *Phil.*
Trigonia denticulata, *Ag.*
—— Phillipsi, *L. & M.*
—— sculpta, *Lyc.*
—— signata, *Ag.* var. Zietenii, *Lyc.*
—— tenuicosta, *Lyc.*
Unicardium depressum, *Phil.*
—— gibbosum, *L. & M.*

GASTEROPODA.

Actæon Sedgvici, *Phil.*; var. pullus, *L. & M.*
Actæonina cinerea, *Hud.*
—— glabra, *Phil.*
—— tumidula, *L. & M.*
Alaria hamus, *Desl.*; var. Phillipsii, *d'Orb.*
Cerithium Beanii ?, *L. & M.*
—— gemmatum, *L. & M.*
—— muricatum, *Sow.*
Chemnitzia lineata, *Sow.*; var. scarburgensis, *L. & M.*
Cloughtonia (Phasianella) cincta, *Phil.*
Eulima lævigata, *L. & M.*
Littorina (Turbo) Phillipsii, *L. & M.*
Natica adducta, *Phil.*
Nerinæa cingenda, *Phil.*
Nerita costulata, *Desh.*
Phasianella latiuscula, *L. & M.*
—— striata, *Sow.*
Purpurina (Turbo) elaborata, *Bean.*
Trochus Leckenbyi, *L. & M.*
—— monilitectus, *Phil.*

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* Mr. Hudleston gives this species, Proc. Geol. Assoc. vol. iii., p. 315, but Dr. Lycett states there is no evidence that it has ever been found below the Cornbrash, Gt. Ool. Moll., Supplement, p. 80,

CEPHALOPODA.

Ammonites Blagdeni, *Sow.*
—— Braikenridgii ?, *Sow.*
—— Brocchii, *Sow.*
—— humphriesianus, *Sow.*
—— Parkinsoni, *Sow.*
—— subcoronatus, *Oppel.*

Belemnites aalensis, *Voltz.*
—— anomalus, *Phil.*
—— giganteus, *Schlot.*
—— quinquesulcatus, *Blain.* (B. compressus, *Sow.*).

REPTILIA.

Cetiosaurus longus, *Owen.*
Ichthyosaurus, sp.

Plesiosaurus, sp.

CHAPTER X.

THE LOWER OOLITES—*continued.*

UPPER ESTUARINE SERIES.

Synonyms:—"Ironstone and Sandstone" (part), Young and Bird, Geol. Sruvey of the Yorksh. Coast, p. 90, 1822; "Upper Sandstone, Shale and Coal," Phillips, Geol. of Yorksh., p. 33, 1829; "Upper beds of the Coaly Grit," Smith, Map of the Hackness Hills, 1832; "Upper Sandstone and Shale," Williamson, Trans. Geol. Soc., ser. 2, vol. vi., p. 143, 1842; "Upper Shales and Sandstones," Wright, Quart. Journ. Geol. Soc., vol. xvi., p. 28, 1860; "The Upper Shale and Sandstone," Hudleston, Proc. Geol. Assoc., vol. iii., p. 318, 1874; "Upper Estuarine Series," Expl. 95 S.W. (Geol. Survey), p. 3, 1880.

As these beds occur between the Grey Limestone which is of Inferior Oolite age and the Cornbrash which belongs to that of the Great Oolite, it is doubtful to which of these horizons they should be referred; and, from the fact of their containing no marine fossils, it is impossible to correlate them with any of the foreign strata deposited at the same time but under different conditions.

The limits of this series are better defined, by the two marked beds above and below, than either of those previously described. It is only in the extreme south where the Grey Limestone dies out that the base becomes at all doubtful, and here the whole of the Lower Oolites are so attenuated that the Estuarine beds merely form thin bands between the more prominent marine strata. The top of the series, throughout the east and north, is well defined by the Cornbrash; and even in the west and south, where we have not been able to recognise this bed, the Kellaways Rock forms nearly as clear a boundary, although the base of this formation being shaly there may be some doubt within a few feet as to where to draw the line.

The Upper Estuarine Series consists principally of shale with a few irregular bands of sandstone of little commercial importance, and one or more beds of granular ironstone. These rest on a massive bed of sandstone, which on account of its development over the moorlands has been called the "Moor Grit." This series is on the whole more shaly than either of those below, and across the interior gives rise to the wettest land of any of the Oolites.

These beds first appear in the scars and lower part of the cliff at Gristhorpe Bay, where the following section occurs.

This gives a total thickness of about 125 feet, but further north below Wheatcroft, judging from the height of the cliff, they must be fully 200 feet in thickness.

Cliff Section measured in Gristhorpe Bay.

	FT.	IN.
Shale with two bands of thin sandstone - -	50	0
Strata probably shale but much obscured by landslips	38	0
Beds mostly sandstone; forms the first reef in the bay	15	0
Granular ironstone band - - - - -	1	0
Sandstone with coaly streaks and sulphur - -	20	0
Total -	124	0

The sandstones which predominate mostly in the lower part are excessively false-bedded, large masses 20 feet or more in thickness, frequently thinning out and passing into shale in as many feet horizontally. In the lower part of the cliff just south of White Nab, this irregularity of bedding is most striking; in the same block of sandstone the upper layers, which are nearly horizontal repose on others inclined at an angle of 30°; this irregularity of bedding produces most curious curves on the low-water scars, north of Scarborough.

The upper portion of these measures is mostly shale with thin sandstones, and can be well studied in the cliffs south of Scarborough, or inland at the clay works near Falsgrave: at these works the sandstones and shales are all ground up together and form a most excellent material for making bricks and draining pipes.

The granular ironstone band in the lower part of the series, which is well exposed on the shore in Gristhorpe and Carnelian Bays, in the cliffs north of Scarborough, and at one or two places in the interior, varies from about 9 inches to a foot in thickness. This ironstone is very irregular; it occurs both as a continuous bed and also as detached nodules, which are generally imbedded in shale, but frequently the ironstone is found covering a bed of sandstone. The character of the rock is very peculiar, it consists of grains of ironstone cemented together in a greenish grey matrix which gives it the appearance of an oolite, although when examined under a lens the grains are seen to have an irregular outline; a coarse variety of the bed is almost botryoidal in structure. The rock contains wood, but we have not found any other organic remains, although Young and Bird state that shells are occasionally found. According to these authors the rock contains 15 per cent. of iron, and was in former times sent to Newcastle to be smelted.*

The sandstones in the lower part of this series contain a few impressions of plants, but they are not nearly so rich in these remains as the Lower and Middle Estuarine Series. The following species are found in these beds.

CRYPTOGAMIA.	
Asplenium petruschiense, Heer. -	White Nab.
Pecopteris acutifolia, L. & H.‡ - -	Red Cliff.
Phlebopteris Woodwardii, Leck.§ - -	White Nab.
GYMNOSPERMÆ.	
Baiera gracilis, Bunbury§ - - -	Scalby.
—— (*Cyclopteris*) *longifolia*, Phil. § -	Scalby and White Nab.
Czekanowskia rigida, Heer. - - -	White Nab.
Ginkgo (*Cyclopteris*) *digitata*, Brong.§ -	Scalby.
—— *Huttoni*, Sternb. - - -	Scalby.
Nilssonia (*Pterophyllum*) *compta*, Phil.§ -	White Nab.
Pterophyllum rigidum, Phil. - -	North Bay, Scarborough.
Solenites furcata, L. & H.† - -	Scalby.

* Young and Bird, Geol. Survey of the Yorksh. Coast. 2nd Ed., p. 96. Phillips mentions that this bed was computed to yield 2,500 tons in an acre. Geol. of the Yorksh. Coast. 3rd Ed., p. 112.

† Occurs also in the Lower Estuarine Series.

‡ The occurrence of this species in the U. E. S. is doubtful, *see* note, p. 219.

§ Occurs also in the Middle Estuarine Series.

The Upper Estuarine Series are by far the most barren in organic remains of all the Lower Oolites; and even in these strata it is only quite in the lower part that the above few species of ferns, cycads, and coniferæ have been found in any abundance. For some reason, which at present is not very apparent, the conditions that prevailed during this period do not appear to have been so favourable for plant life as those which preceded it. Of the above species only about half have continued from the series below.*

In Gristhorpe Bay the upper beds are mostly hidden by talus from the cliff, but the lower part of the series is well exposed in the low cliff at the end of the bay and along the inner part of the scars below the beach. In Cayton Bay these beds scarcely come to the surface, but north of Osgodby Nab the strata rapidly rise; and, although much hidden by Boulder Clay in Carnelian Bay, are very clearly exposed in the cliffs beyond White Nab.

Between this point and Scarborough the excessively false-bedded character of the sandstones in the lower part of the series is better seen than anywhere else throughout their entire outcrop, thick masses of sandstone changing into shale at very short distances, while the intermixture of shale and sandstone with thin ironstones and carbonaceous fragments is very curious; the beds also frequently assume a regular basin-shaped form, filling old hollows cut in these strata, in fact, a better instance of the effect of changing currents on beds deposited under these conditions can scarcely be obtained. It is also interesting to notice the effect of the oxidation of the iron in some of the sandstones; these which were originally grey become gradually changed towards the exterior to various shades of brown and yellow arranged in concentric circles, producing most exquisite patterns, which have a striking resemblance to a map on which the contours have been represented by different shades of colour; these are sometimes well exposed on the shore when it has been bared of sand.

The sandstone towards the base of the series contains the impressions of certain bivalve shells, which may be seen depending from the roof of some of the caves near Scarborough. These were originally referred to *Unio*,† but from the hinge being edentulous have since been stated to be an *Anodon*.‡ From this circumstance the beds between White Nab and the Spa have been considered to be the remains of an extensive freshwater lake,§ but as the shells are only casts it is doubtful whether they are freshwater species at all, and may possibly be *Myacites*, which we have noticed occurs at about this horizon. In either case it is evident that these strata were deposited in very shallow water, which possibly oscillated between freshwater and estuarine con-

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* Owing to the confusion which formerly existed as to the different divisions of the Estuarine Series, it is not possible to be sure from what horizon many species were originally obtained.

† *Unio insperatus*, Phil. MS. Geol. of Yorksh. Coast, 3rd Ed., p. 251.

‡ Proc. Geol. Assoc., vol. iii., p. 318.

§ Leckenby. Quart. Journ. Geol. Soc., vol. xx., p. 75.

ditions, or possibly that the two prevailed simultaneously, shallow lagoons being formed here and there along the margin of the estuary. North of Scarborough the false-bedded character of the sandstones, which form the extensive scars along the shore, is so strongly marked, that the contrary courses of the different beds can be easily followed from the cliff above.

At Scalby Ness these sandstones have yielded the majority of the plants which have been found in this series. Here also the granular ironstone band again comes in, and may be noticed at intervals along the Burniston cliffs, but these cliffs are too much obscured by Drift to be sure how far it is continuous.

To the south of Cloughton Wyke the Upper Estuarine Series leaves the cliff and passes inland along the foot of the Hackness Hills, and thence across Fylingdales Moor to Goathland; forming a broad tract of cold desolate moorland, except near the coast, where there is a thick covering of Drift, which considerably improves the character of the land and renders it fit for cultivation.

The Moor Grit, at the base of the series, is first seen in Gristhorpe Bay and along the lower part of the cliff from White Nab to Scarborough, but it is not so massive and distinctive a rock as further north, and therefore scarcely worth separating from the softer beds above.

About Cloughton and in the Staintondale cliffs it becomes better developed, forming a somewhat conspicuous feature to the west of Cloughton, across Harwood-dale Moor, and along the range of hills to the south-west of Robin Hoods Bay. Beyond this it skirts round the head of Maybecks, and passing over Sleights Moor descends into lower ground near Goathland, crossing the railway not far from the summit level.

The Moor Grit in this district makes an excellent building stone, being quarried at Cloughton, on Harwood-dale Moor, and other places, while at Sneaton it forms large flags from which the great paving slabs at Whitby Quay were derived.

*About Whitby and north of the Esk, the Moor Grit is a hard white silicious rock, much worked for different purposes, according to its local character. Many of the most durable buildings are made of it, and in the central part of this area it forms a very hard road-metal. It is seen in Beacon Hill and Moorgate Lathes to the east of Whitby, and again about the ship-yard and in Larpool Woods, where it is well developed.

It is also evidently of considerable thickness on the opposite side of the Esk, where the new railway cutting passes through this bed.

At the north-east end of the great Cleveland outlier, the Moor Grit has been quarried about East and West Barnby, where it is very hard and is used for road-metal, but at the head of Barnby

* The description of the northern area is taken from the account given by Mr. Barrow in the Memoirs of the Geological Survey, Explanations of 95 N.W., 96 N.E., and 104 S.W.

dales, north of Mickleby, it is a softer siliceous stone, and is quarried for building purposes. Over Ellerby Moor and Newton Mulgrave it has been worked for road-metal for many years, occurring in thin wedges, very hard, and breaking like a chert. It is known locally as the "White Flint." When fragments of this rock weather out on the moor they have quite a glassy surface, and appear almost indestructible. These are the rocks which have been called "Crow-stones" although the name has probably also been applied to other beds besides the Moor Grit. Young and Bird state that, owing to its durability, this is the material of which several of our ancient rude monuments, consisting of upright unsculptured stones, have been made.* When the roads are mended with this stone the little angular glassy lumps stick up and make them very painful to walk over.

About Rousby Mill, where the Moor Grit is of great thickness, the lower portion is flaggy, the middle a hard massive sandstone, wedges of "White Flint" forming the upper part. A little south of this, the middle part is a true gannister with rootlets, and could be easily ground and crushed. About Grinkle Park this bed is a thick gritty sandstone, and has been extensively used for building. It appears softer and more flaggy at the outcrop in Grinkle Lane, after which it presents no feature of particular interest for some distance.

At Nab End Wood, opposite Kilton Castle, the Moor Grit forms a bold precipitous scar, and is of considerable thickness. This scar continues as far as Liverton Mill, and the rock has been much quarried in its course. It forms the bed of the stream in Cow Close Wood, where it is again flint-like; it also presents a similar appearance in the west bank of Hagg Beck. Kilton village stands on the Moor Grit, which is seen in several places about Lumpsey. It was passed through in North Skelton shaft, and a considerable quantity of the hard "White Flint" was met with in the water level of that mine. Wygrave Quarry is in this bed which must make a considerable spread under the Drift here, for it was the first rock met with in sinking Lingdale pit. There are numerous openings in it on Stanghow Ridge, and about Kate Ridding; Pissing Scar, near the latter place, is also formed by it. There are several quarries about Tidkinhow, and a very fine section is exposed at the head of Lockwood Gill, where the "White Flint" at the top is well developed.

Blocks of white grit with a glassy surface mark the outcrop over Commondale, on the east side of which, the "White Flint" has been quarried, occurring in wedges in the softer grit. This bed maintains a very uniform character in the great bank overlooking the Esk on the north side. About Danby the numerous quarries for road-metal mark its position well. Some of these fragments of the White Flint are so compact and semi-crystalline

* Young and Bird. Geol. Survey of the Yorksh. Coast. 2nd Ed., p. 104.

as to be translucent in thin flakes. A specimen from the quarry above the road going from Danby Station to Easington was given to Mr. J. A. Phillips, who thus describes it.* "It is white and fine-grained, being often so compact as to be entitled rather to the name of quartzite than to that of grit . . . . . .

"Under the microscope, this rock is seen to be almost entirely composed of transparent colourless quartz, of which the largest pieces are about $\frac{1}{75}$ inch in diameter, and of which the angles are usually more or less removed. Around and between these grains a deposit of transparent crystalline quartz has taken place, thus forming a cementing medium. A few small garnets are present, but no fluid-cavities with bubbles were observed, although some of the quartz encloses minute crystals of a yellowish mineral which I have been unable to identify; these are exceedingly minute, often not exceeding $\frac{1}{10000}$ inch in length. Many of the smaller grains in this rock exhibit, when examined in polarized light, that complex structure so frequently observed in the quartz of clay-slates and other somewhat similar rocks."

Round Lealholm Rigg past Stonegate to the great east and west fault, the road-metal quarries indicate plainly the course of this rock; on the east side of the valley the outcrop can also be easily followed above Westonby House, after which the rock gradually becomes more flaggy, and keeps so for a considerable distance, as may be seen in the quarries south-west of Fishburn's Plantation. On the north side of Egton Low Moor the outcrop is entirely covered by Drift, and can only be approximately fixed.

Calf Hill Crag, near Eller Park, is formed by the Moor Grit which is here a fine massive rock, and continues to form the upper part of the east bank of the stream as far as Eller Park.

This bed has also been worked in Dale Beck Quarry west of Mickleby, where it occurs in thick flags.

On Skelton Hill weathered fragments of the "White Flint" are seen, but the bed as a whole is poorly developed; the same may be said of its outcrop on Eston Moor, where the Grey Limestone Grit overshadows the outcrop of the adjacent rocks.

The Estuarine beds above the Moor Grit in this area consist of thin sandstones and shales. The former are very hard and close grained, being often used for walling and moor enclosures. The latter are scarcely true shales at all, but rather hardened clays, weathering into small prismatic fragments. As a rule, they are nearly white and look rather like putty, but sometimes they are red or mottled, somewhat resembling New Red Marl. They are quite destitute of lime, which causes them to form a very barren soil, being in addition very wet and cold. When ground, a very fine brick can be made from these beds, as may be seen near Egton.

The only exposures about Whitby are in Larpool Woods, and on the west bank of the Esk opposite the ship-yard.

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* Quart. Journ. Geol. Soc., vol. xxxvii., No. 145, p. 16.

On the great central plateau, the chief exposures are in the various streams between Mickleby and Ugthorpe, and in Wapley and Cow Close Becks.

About Kilton Pit the shales are exposed in the railway cutting and on several of the small surrounding hills. Some of this shale when ground and burnt was found to make a durable fire-brick. About Danby Beacon some of the footpaths have been deepened by the rain, and a nearly complete section can be seen on the west side of the hill. As the country is quite free of Drift, the kind of ground that these beds form can be easily studied. The cold wet white shale is seen between the roots of the ragged heather, which has all the appearance of struggling for existence. A great spread of these strata gives a dreary landscape that is not easily forgotten. Within a few feet of the top of this series is a bed of hard white compact grit, very like the "White Flint." Its hardness causes its outcrop to be very clear when free of Drift, and fixes very well the upper limit of the Estuarine beds, but it is so frequently drift-covered, except where it rises to more than 800 feet above the sea level, that there are very few exposures of this series.

South of the Esk there is a large spread of the Estuarine Series over Wheeldale and Pickering Moors; but west of the Seven valley, from the increase in the dip of the beds, they occupy only a narrow band along the foot of the Tabular range. In this area the Moor Grit varies very much, the quartzite-looking beds being only occasionally visible; in which case the moor is strewed with white blocks having a very glassy-looking surface. Below this part of the bed is a solid white freestone, which becomes very hard on exposure to the atmosphere and affords an excellent building stone. Being well-bedded it is fairly easily worked, and was quarried at Old Fold on Helmsley Moor to build the bridges of the North-eastern Railway between Helmsley and Pickering, which structures are evidence of the fine blocks that can be obtained from it. Except that they are here somewhat thinner, and contain rather more sandstone, the Estuarine Beds above the Moor Grit offer no point of interest on the Helmsley Moors.

West of Bilsdale, and along the western escarpment of the Hambleton Hills, there are not much more than one hundred feet of these beds, although about Hawnby the thickness seems to be somewhat greater. The upper portion, as a rule, makes wet clayey slopes, at the base of which the Moor Grit forms a distinct feature, often covering a considerable area of moorland. The outcrop of the Moor Grit follows that of the Grey Limestone so closely that it frequently merely forms the upper part of that feature, and the description of one does for that of the other; but in a few cases, as on Bilsdale West Moor, Hawnby Moor, and over part of Snilesworth Moor, where this grit is partly of a gannister nature, it runs out in broad tongues, in a similar manner to the fossiliferous grit below, the ground being covered with large white siliceous blocks.

The shaly portion of this series does not generally afford good sections, their outcrop, which is principally below the steep escarpment of the Middle Oolites, only forms a narrow belt which is usually buried by the landslips and débris from that formation. The beds are, however, seen in some of the deeper valleys about Hawnby, and also on Osmotherley and Boltby Moors, where they run out from the overlying beds, and cover a wider area.

There are a few quarries in the grit along this bank, but the bed is considerably softer than over the northern moorlands, and not of much value as a building stone.

Throughout the Howardian Hills the Upper Estuarine Series is of very little importance, it consists mostly of sand which towards the base becomes more solid, and in a few places is almost a grit, the upper portion is, however, more clayey. These beds crop out in the low ground at the foot of Gilling Park, between the faults south of Sike Gate, and below Hovingham High Wood, as far as Hovingham Lodge; beyond this they are cut out by the fault as far as Wath Beck, but again form a tract of sandy land by Gay's Hall and Slingsby Moor, until they meet the fault north of Coneysthorpe. There are also outliers in Newburgh Park, at Yearsley, and at Brandsby.

By the great Coneysthorpe fault these beds are repeated at Ling Hills near Terrington, but south of Castle Howard are cut out for some distance, and only appear again very indistinctly to the west and south of Hutton. In the neighbourhood of the Derwent all the Estuarine Series are so thin that they only represent narrow sandy divisions between the more apparent bands of limestone.

In South Yorkshire there are a series of sands and clays between the Cave Oolite and the Kellaways Rock, which occupy a similar position to the Upper Estuarine Series of the Yorkshire basin. These beds, which have been considered to be of Great Oolite age from the fact of their outcrop being continuous with the clays of that formation in the district to the south of the Humber, have a thickness of from twenty to thirty feet, and consist mostly of sand, clayey in part. They were passed through in the well at the cross roads north of South Cave, of which the following is the complete section:—

Well at Drewton Stray Cottage.

	Ft.	In.
Top soil.		
Clayey soil	5	0
Hard red and white sand with large stone boulders	25	0
Blue shaly clay, in which water lodges	3	0
Sand	16	0
Rock	20	0
Very hard blue clay	2	0
Blue shaly clay	2 0 to 3	0

This clay was bored into from 10 ft. to 12 ft. without reaching the bottom.

The sands which are classed with this formation are first seen at the village of Sancton, where they have been dug. In the pit

behind the church the beds are dipping at a high angle, about 12 degrees, thus showing the great unconformity between it and the Chalk which has not nearly so high a dip. In this pit the limestone was met with at 30 feet, and a well at Sancton Grange just above is said to be 90 feet in Chalk and limestone; but whether the sand was met with is not stated; if not, the outcrop to the north must terminate very sharply.

The only other place where these beds are well exposed is in the railway cutting east of the road at Drewton. Here the upper part of the formation is seen, but the beds are so similar to the sands of the Kellaways Rock above that it is difficult to fix an exact horizon between them.

The outcrop of these sands and clays forms a narrow band beneath that of the Kellaways Rock, but there is nothing of special interest about it, and it can be best followed in tracing that formation.

CHAPTER XI.

THE LOWER OOLITES—(*continued*).

CORNBRASH.

Synonyms and Foreign Equivalents.—"Cornbrash," W. Smith, Map of England, 1815; "Cornbrash Limestone," Phillips, Geol. of the Yorkshire Coast, p. 33, 1829; "Calcaire schistoïde," Brongniart, Tableau des Terrains, p. 225, 1829; "Calcaires roux sableaux," Thurmann, Essai sur les soulèvemens, p. 29, 1830; "Calcaires a oolithes oviformes," Thurmann, Statistique de la Haute-Saone, p. 184, 1833; "Assise supérieure de l'étage bathonien," Cotteau, Geol. du départ. de l'Yonne, 1847; "Die Schichten der *Terebratula lagenalis*" and "Die Schichten des *Ammonites macrocephalus*," (part), Oppel, Juraformation, pp. 454, 507, 1856; "Dalle nacrée et calcaire marneux inf. à *Pentacrinus Buvignieri* et *Heteropora conifera*" and "Calcaires suboolithiques et marnes à *Terebratula digona, obovata, ornithocephala* et *intermedia*," Martin, Soc. Géol. de Fr., 2e ser., t. xviii., p. 640, 1861; "Calcaires compactes avec *Lithophaga* et *Ostrea*," Ferry, Mem. Soc. Linn. de Norm., vol. xii., 1861; "Der Eisenkalk und Shieferthon des Cornbrash mit *Avicula echinata*," Von Seebach, Der Hannoversche Jura, p. 42, 1864; "Die oolithischen Mergel und Eisenkalke mit *Avicula echinata*," Brauns, Der mittlere Jura, p. 56, 1869; "Cornbrash" and "The Shales with *Avicula echinata*," Hudleston, Proc. Geol. Assoc., vol. iii., p. 319, and vol. iv., p. 360, 1874–6.

Origin of the name.—"Cornbrash" is the old agricultural name given by William Smith to the thin band of rough shelly rock, which in the southern counties breaks up into a loose rubble or "brash," forming good land for growing "corn" and other grain.

This name is however rather inappropriate in the Yorkshire district; as, owing to the thick sandstones which occur at a short distance above, this bed only crops out in the steep cliffs or escarpments formed by these more massive sandstones; and consequently, never being exposed over any breadth of area, is of no importance from an agricultural point of view.

It has been considered somewhat uncertain whether the Yorkshire Cornbrash occupies precisely the same horizon as that of the district where it obtained its name; and that it is doubtful whether it is really the exact equivalent in time of the Cornbrash of the South of England, or if it rather represents an extension of the Great Oolite Series. Prof. Judd in his memoir on the Geology of Rutland, says "The so-called Cornbrash of the North of Yorkshire is not only not continuous with that of the South and Midland districts of England, but, as shown by Dr. Lycett, presents essential points of difference from that formation in its mineral character, and still more striking ones in its fauna."* And further on he remarks "In North Yorkshire the only representative of the Great Oolite Series appears to be the thin limestone bands with associated clays, known as the 'Cornbrash of Scarborough,' which must not be confounded with the Cornbrash of the rest of England, with which it happens to present some points of mineralogical resemblance."† Dr. Lycett in the memoir referred to below‡ remarks on the abundance and perfec-

* Geological Survey Memoirs, Geology of Rutland, p. 9.

† *Ibid.*, p. 187.

‡ Supplementary Monograph on the Great Oolite Mollusca, Pal. Soc. for 1861, p. 117.

tion of the Conchifera in the Yorkshire rock, and the great scarcity of Brachiopoda; while the Cornbrash of the South is crowded with Brachiopoda and "the Conchifera are usually in the condition of casts of which a large proportion are compressed and distorted."

There is, however, not much doubt as to the relative age of the Yorkshire rock; for now that more extensive lists of fossils have been obtained from southern localities, it appears that the correspondence between the two is much greater than was originally supposed. Thus by comparing the list of species obtained from the Yorkshire Cornbrash with those from the South of England, it will be seen that 57 per cent. are common to the two, while not more than 28 per cent. are found in the Great Oolite; at the same time 48 per cent. pass into higher formations, while only 43 per cent. are found in those below; so that the Cornbrash is really more intimately connected with the overlying beds than with those beneath, the fact of the matter being that this formation biologically represents a passage from the Lower into the Middle Oolite.

In the Yorkshire Cornbrash there are only four species of Brachiopoda that are at all common, namely, *Waldheimia lagenalis*, *W. obovata*, *Rhynchonella Leedsii*, and *Terebratula intermedia*; but individuals, especially of the two former, are by no means rare. The Mollusca taken as a whole are intimately related both to those of the Inferior Oolite and to the beds above, and "may be regarded as a transitive series, a chain of life serving to connect the fauna of the Inferior Oolite with that of the Oxfordian rocks,"* although the Cephalopoda mark a decided break in the continuity.

The Cornbrash, which is wonderfully uniform both in thickness and character throughout the South and Midland counties, becomes much thinner in North Lincolnshire and presents the aspect of having been deposited under somewhat different conditions. In the neighbourhood of the Humber it probably dies out altogether; and in South Yorkshire, where the horizon of this bed rises above the Drift and Alluvium, and fairly good sections are obtained, there is not a trace of it, nor in fact of any fossiliferous band between the limestone of the Inferior Oolite and the Kellaways Rock.

Further north the whole of the Oolites are hidden by the overlap of the Cretaceous beds, so that it is not possible to say what takes place in the interval, although it is not probable that there can be any representative of the Cornbrash as we have to follow the horizon of this bed a long way on the north side of the overlap before obtaining any indications of a fossiliferous band.

Throughout the Howardian Hills, along the southern edge of the Yorkshire basin there is no trace of a marine bed between the Estuarine Series of the Lower Oolites and the Kellaways Rock, nor is there much evidence of its existence along the western escarpment. In fact it is only along the northern outcrop, or north of a line running slightly to the north of west from Filey

* Lycett, loc. cit., p. 118.

that this rock is recognized. Across this region it has been traced fairly continuously, and there are numerous exposures of the rock from the point where it first rises above the level of the sea near Filey, till it is finally lost sight of in the Hambleton Hills, besides the several outliers which occur on these moors and the important outcrop beyond the Esk to the west of Whitby.

In mineral character the Cornbrash consists of a thin band of hard ferruginous limestone crowded with fossils, which becomes softer and more earthy below, and passes down into calcareous shales with but few fossils. The whole of these are not more than from 1 to 2 feet thick where exposed on the shore, but at Wheatcroft and further inland the beds are thicker and more compact, increasing to as much as 7 or 8 feet in Newtondale. Resting on this thin band of rock are from 6 to 8 feet of dark coloured shales containing a few fossils from which the following species are said to have been obtained.

Hemipedina Woodwardi.	Lima rigidula.
Eryma Birdii.	—— sulcata.
Glyphæa Stricklandi.*	Pecten lens.
Serpula, sp.	—— demissus.
Rhynchonella Leedsii.	Modiola cuneata.
Waldheimia lagenalis.	Pholadomya, sp.
Avicula echinata.	Goniomya literata.
—— sp.	Gresslya peregrina.
Gryphæa, sp. (young).	Ammonites macrocephalus.

These which are the so-called "Clays of the Cornbrash" are very similar in petrological character to the lower part of the Oxford Clay, and no doubt foreshadow the physical conditions of that deposit. They pass up into more sandy shales which appear to be nearly destitute of fossils, and finally blend with the shaley base of the Kellaways Rock, so that no very exact line can be drawn between the two. The junction at the base of these shales with the hard limestone below is usually marked by a reddish band of rotten ferruginous shale, probably caused by the percolation of water along this line.

The small list of fossils that have been obtained from these shales are too meagre to afford very definite evidence as to what

* The Crustacea derived from these beds have not as yet been properly determined. Dr. Wright mentions *Glyphæa rostrata* and *G. Birdii* from these beds. Dr. Carter states that the type of *G. Stricklandi* has been referred to the wrong genus. Among the Lamellibranchiata *Anatina parvula*, *Cardium latum*, and *Opis triangularis* have been included in the list of fossils from these shales, but this is an error, as appears from the following note by Mr. Leckenby in Dr. Wright's "Correlation of the Jurassic Rocks of the Côte d'Or and the Cotteswold Hills," Cottesw. Nat. Club, August 1869, p. 208. "*Sanguinolaria parvula* and *Cardium latum*:—These very doubtful species, founded on solitary examples, are really unworthy of being continued in any list of Cornbrash fossils. The first is no true Sanguinolaria. *Opis triangularis*, Bean, is hardly even a variety of *Isocardia nitida*, Phillips; it is not an Opis; and I have struck it out of my list of Cornbrash fossils. *Ammonites macrocephalus*, Schlot., is not peculiar to the clay, but is found much more abundantly in the true Cornbrash below. The only characteristic fossil, therefore, is the species referred to *Belemnites tornatilis*, Phillips; but I cannot refer it to any of the varieties of *B. Owenii* in which Prof. Phillips now includes *B. tornatilis*,—it comes nearer to *B. abbreviatus*." Prof. Phillips considered the occurrence of Belemnites in the Cornbrash as very doubtful. *See* Pal. Mon. on British Belemnites, p. 109

horizon they should be assigned; most of the species have a wide range and are consequently of little value. On the Continent in N.W. Germany, where the equivalent of these shales is supposed to occur, they appear to be classed with the Cornbrash and therefore included in the Middle Jura.

With regard to the palæontological character of the Cornbrash the first thing that strikes us is the abundance and good preservation of its fauna. The rock, although physically of so little importance, is palæontologically one of the most interesting beds in the whole range of Oolites. For, as will be seen from a glance at the following list of fossils, although there is a marked absence of Cephalopoda, the profusion of other mollusca is very remarkable. The closing scene of the Lower Oolite was the richest in marine life of the whole period. This is especially the case in the two groups of Lamellibranchiata and Gasteropoda. The Echinodermata are also well represented and very characteristic; while the Brachiopoda, which have been very rare since the lower part of the Inferior Oolite, again become more plentiful.

The following list of fossils comprises those species that have been found in the Cornbrash of Yorkshire, with the exception of the few forms that seem to be confined to the overlying shales:—

Fossils from the Cornbrash.

SPONGIDA.

Stellispongia, ? sp.*

ACTINOZOA.

Caryophyllia, sp.
Isastræa, sp.*

ECHINODERMATA.

‡Echinobrissus clunicularis, *Llhwyd.*
‡—— orbicularis, *Phil.*
Hemipedina Woodwardi, *Wr.*
‡Holectypus depressus, *Leske.*
Pseudodiadema pentagonum, *M'Coy.*
—— vagans, *Phil.*

ANNELIDA.

Serpula clava, *Bean, MS.*
‡—— intestinalis, *Phil.*
—— lacerata, *Phil.*
‡Serpula squamosa, *Phil.*
‡—— tetragona, *Sow.*
Vermicularia nodus, *Phil.*

CRUSTACEA.

Eryma (Glyphæa) Birdii, *Bean, MS.*
‡Glyphæa rostrata, *Phil.*
—— Terquemi, *Oppel.*

POLYZOA.

‡Diastopora ? sp.
Hippothoa (Cellaria) Smithii, *Phil.*
‡Entalophora (Spiropora, Cricopora) straminea, *Phil.*

BRACHIOPODA.

Discina annulosa, *Dav.*
‡Rhynchonella concinna, *Sow.*†
—— socialis, *Phil.*†
‡—— varians, *Schlot.*†
‡—— Leedsii, *Walker.*
‡Terebratula Bentleyi, *Dav.*
‡Terebratula intermedia, *Sow.*
‡Waldheimia lagenalis, *Schlot.*
‡—— obovata, *Sow.* var. siddingtonensis, *Walker.*
‡—— obovata, var. stiltonensis, *Walker.*

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* See Table II. in Volume II.

† These determinations should probably be included under *Rhyn. Leedsii.*

‡ These species occur in the Cornbrash of other parts of England, and are so notified by Mr. H. B. Woodward.

LAMELLIBRANCHIATA.

‡Avicula braamburiensis, *Sow.*
‡—— echinata, *Sow.*
‡—— Münsteri, *Goldf.*
—— ornata, *Goldf.*
‡Exogyra nana, *Sow.* (Gryphæa mima, *Phil.*).
‡Gervillia aviculoides, *Sow.*
—— tortuosa, *Phil.*
Gryphæa dilatata, *Sow.*
Hinnites gradus, *Bean.*
‡Lima duplicata, *Sow.*
‡—— helvetica, *Oppel.*
‡—— impressa, *L. & M.*
—— interstincta, *Phil.*
‡—— pectiniformis, *Schlot.* (L. proboscidea, *Sow.*).
‡—— punctata, *Sow.*
‡—— rigidula, *Phil.*
—— rudis, *Sow.*
‡Ostrea flabelloides, *Lam.*
—— Meadii, *Sow.*
—— solitaria, *Sow.*
—— spatiosa, *Bean, MS.*
‡Pecten anisopleurus, *Buv.*
‡—— arcuatus, *Sow.*
‡—— articulatus, *Schlot.*
—— cingulatus, *Goldf.*
‡—— demissus, *Phil.*
‡—— inæquicostatus, *Phil.*
‡—— intertextus, *Röm.* (P. cancellatus, *Bean*).
‡—— lens, *Sow.*
—— subfibrosus ?, *d'Orb.*
‡—— vagans, *Sow.*
Perna obliqua, *Lyc.*
‡—— rugosa, *Goldf.*
‡Pinna cuneata, *Bean.*
‡—— lanceolata, *Sow.*
Placunopsis inæqualis, *Phil.*
‡—— (Anomia) semistriatus, *Bean.*
—— (Ostrea) granulata, *Bean, MS.*
Trichites sp.
‡Anatina plicatella, *L. & M.*
—— siliqua, *Ag.*
‡Astarte elegans, *Sow,*
—— extensa, *Phil.*
‡—— Leckenbyi, *Wr.*
‡—— politula, *Bean.*
—— robusta, *Lyc.*
‡—— ungulata, *Lyc.* (A. lurida, *Phil.*).
‡Cardium citrinoideum, *Phil.*
‡—— cognatum, *Phil.*
—— globosum, *Bean*
—— lobatum, *Phil.*
—— Sowerbyi, *Lyc. MS.* (Isocardia minima, *Lyc.*).*
Corbicella ovalis, *Phil.*
—— subæquilatera, *Lyc.* (Corbis lucida, *Bean*).
Cucullæa cancellata, *Phil.*
Cucullæa clathrata, *Leck.*
—— concinna, *Phil.*
—— corallina, *Damon.*
Cypricardia rostrata, *Sow.*
‡Goniomya literata, *Sow.*
—— sulcata, *Ag.*
‡—— v-scripta, *Sow.*
Gresslya abducta, *Phil.*
‡—— peregrina, *Phil.*
‡Homomya crassiuscula, *L. & M.*
‡Isoarca scarburgensis, *Lyc.*
‡Isocardia minima, *Sow.*
—— nitida, *Phil.* (I. triangularis, *Bean*).
—— tenera, *Sow.*
Leda anglica, *d'Orb.* (Nucula lachryma, *Phil.*).
‡—— lachryma, *Sow.*
Lucina Beanii, *Lyc.*
‡—— bellona, *d'Orb.*
—— crassa, *Sow.*
‡—— despecta, *Phil.*
‡Modiola bipartita, *Sow.*
‡—— cuneata, *Sow.*
‡—— imbricata, *Sow.*
Myacites Beanii, *L. & M.*
‡—— calceiformis, *Phil.*
‡—— decurtatus, *Phil.*
—— decussatus, *Bean, MS.*
—— Goldfussii, *Lyc.*
—— modicus, *Bean.*
‡—— recurvus, *Phil.*
‡—— securiformis, *Phil.*
‡—— sinister, *Ag.*
‡Mytilus sublævis, *Sow.*
‡Nucula subglobosa, *Röm.*
‡—— variabilis, *Sow.*
‡Opis Leckenbyi, *Lyc.*
‡Pholadomya acuticosta, *Sow.*
—— angustata, *Sow.*
‡—— Heraulti ?, *Ag.*
‡—— ovalis, *Sow.* (Ph. nana, *Phil.*).
‡—— ovulum, *Ag.*
‡—— Phillipsii, *Morris.*
—— simplex, *Phil.*
‡Pholas costellata, *L. & M.*
‡Quenstedtia lævigata, *Phil.*
‡—— oblita, *Phil.*
‡Sowerbya triangularis, *Phil.*
Tancredia donaciformis, *Lyc.*
‡Trigonia cassiope, *d'Orb.*
‡—— elongata, *Sow.*, var. angustata, *Lyc.*
‡—— —— var. lata, *Lyc.*
—— Moretoni, *L. & M.*
‡—— scarburgensis, *Lyc.* (T. clavellata, *Auct.*).
—— signata, *Ag.*
Unicardium depressum, *Phil.*
—— sulcatum, *Leck.*

* See Volume

SCAPHOPODA.

‡Dentalium entaloides, *Desl.*

GASTEROPODA.

Actæon Sedgvici, *Phil.* var. pullus, *L. & M.*
‡Actæonina scarburgensis, *Lyc.*
Alaria bispinosa, *Phil.* var. elegans, *Hud.*
—— myurus, *Desl.* var. teres, *Hud.*
Amberleya armigera, *Lyc.*
‡Bulla (Cylindrites) undulata, *Bean.*
‡Cerithium gemmatum ?, *L. & M.*
—— muricatum, *Sow.*
‡Chemnitzia vittata, *Phil.*
Eulima lævigata, *L. & M.*
Littorina (Turbo) Phillipsii ?, *L. & M.*
Natica insignis, *Lyc.*
‡—— (Littorina) punctura, *Bean.*
Nerinæa cingenda, *Phil.* non *Sow.*
‡—— granulata, *Phil.*
—— sp.
Neritopsis canaliculata, *d'Arch.* (Turbo Archiaci, *d'Orb.*).
—— (Turbo) lævigata ?, *Phil.*
‡Pleurotomaria granulata, *Lyc.*
‡Purpurina condensata, *Heb. & Desl.* (T. elaboratus, *of some Cb. lists*).
Trochus angulatus, *Goldf.*
—— monilitectus, *Phil.*
—— scarburgensis, *Hud.*
‡—— strigosus, *Lyc.*
—— subglaber, *Hud.*
Turbo (Delphinula) funiculatus, *Phil.*

CEPHALOPODA.

‡Ammonites macrocephalus, *Schlot.* (Am. Herveyi, *Sow.*, Am. terebratus, *Phil.*).
Nautilus hexagonus, *Sow.*

PISCES.

Strophodus magnus, *Ag.*

The Cornbrash first rises from the sea at the Wyke, just beyond the southern end of Gristhorpe Bay, between Scarborough and Filey. It is here exclusive of the shales about a foot or rather more in thickness, and forms a small reef running out to sea, parallel with the somewhat larger one of the Kellaways Rock; from which it is divided by a narrow band of soft shales that have been hollowed out and form a small inlet between the two. There is only a small exposure of the rock at this place, and as it is only seen at ebb tide it might be easily overlooked, the outcrop in the cliff being entirely covered up by the débris of the Calcareous Grit and Oxford Clay. The section on the shore which is exposed here and there between the boulders seems to be :—

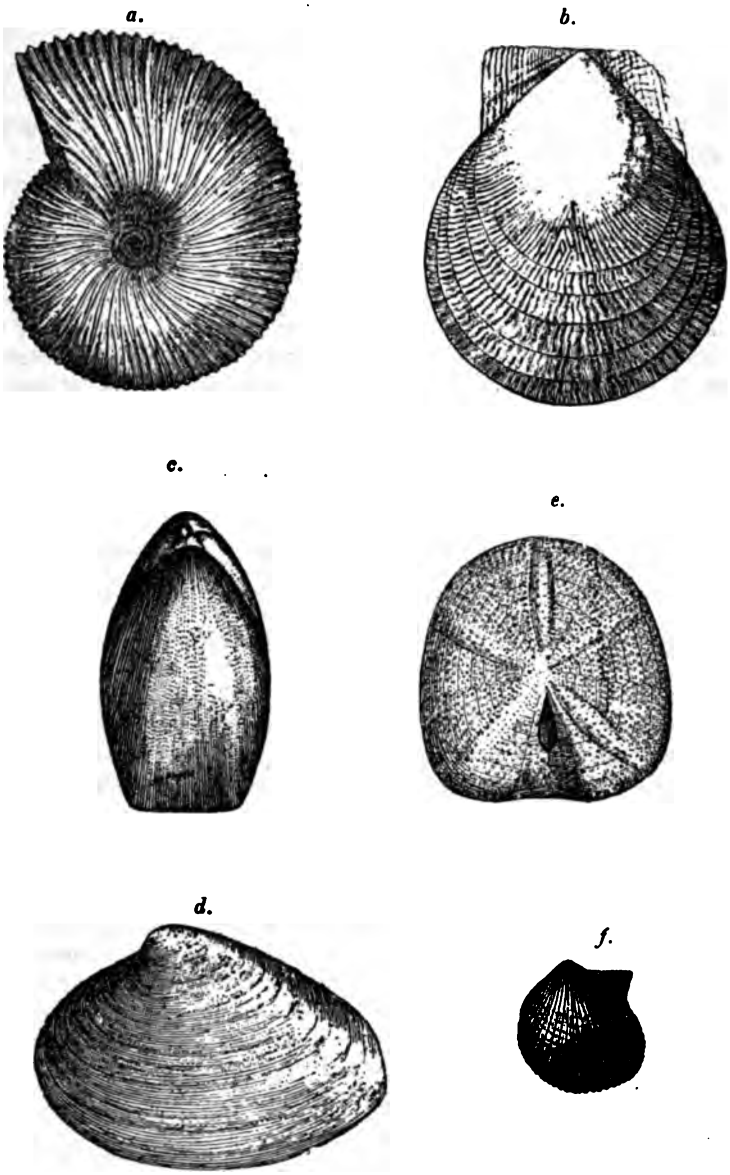
	FT.	IN.
Sandstone of the Kellaways Rock.		
Shaly sandstone passing down into greyish shales - -	1	0
Grey shaly rock with white markings containing many fossils, *Modiola*, *Avicula*, &c.; curious nests of *Belemnites* on top -	1	6
Blue shale, very like Oxford Clay - - - -	a few feet.	
Cornbrash limestone, passing down into soft grey sandstone - - - - - - - -	1 4 to 1	6
Thick sandstone below forming a conspicuous reef.		

In Gristhorpe Bay the Cornbrash begins to rise in the cliff, and is first seen at Great Dike, below Cunstone Nab, where we find above high-water mark the following section :—

			FT.	IN.
Massive sandstone with *Belemnites* and streaks of coaly matter, passing down into shales.				
Shales very fossiliferous in lower part, but the fossils in a rotten condition, *Avicula*, *Mya*, &c. - - -			11	0
	IN.			
Solid limestone - -	9	Cornbrash Rock - -	1	2
Softer and more rotten beds	5			
Estuarine sandstones and shales with a massive bed of sandstone in the centre - -		To high-water mark	18	0

FIG. 13.

Cornbrash Fossils.



a. Ammonites macrocephalus, *Schlot.* (after d'Orbigny) ½; *b*. Pecten lens, *Sow.* (after Lycett and Morris); *c*. Waldheimia lagenalis, *Schlot.* (after Davidson); *d*. Gresslya peregrina, *Phil.* (after Lycett and Morris); *e*. Echinobrissus clunicularis, *Llhwyd* (after Wright); *f*. Avicula echinata, *Sow.* (original) 1½.

Further on in the cliff we have :—

	Ft.	In.		Ft.	In.
Massive sandstone passing down into soft sands.					
Shales, lower portion fossiliferous - - - -				15	0
Red ferruginous shale	0	4	Cornbrash Rock	1	9
Hard limestone	1	0			
Dark fossiliferous shales	0	5			
Clayey shales below					

West of this point the section is hidden by the Boulder Clay till we get to the great fault at Red Cliff.*

It will be seen from these sections that the bed so far has kept pretty uniform, but further west it begins to thicken and become stronger.

In Cayton Bay there are two exposures of the Cornbrash; below Red Cliff, and at the western end of the bay near Osgodby Nab. The first of these is the better known, and is that from which a large part of the fossils from the Yorkshire Cornbrash have been obtained. The rock here forms a long reef at and just below high-water mark, which extends for about 600 yards along the shore and is sometimes much covered up by sand, but frequently is clear nearly the whole way. The following section is exposed :—

	Ft.	In.
Massive soft sandstones of the Kellaways Rock becoming shaly towards the base and passing into—		
Grey shales with *Avicula echinata*, *Glyphæa Stricklandi*, and other fossils - - - - - -	6 0 to 8	0
Cornbrash limestone crowded with *Ostrea flabelloides*, &c., in one solid block - - - - - - -	2	8

At the west end of Cayton Bay there is a small portion of the Cornbrash exposed at ebb tide, close against the large fault which brings up the Millepore Bed at the point, but no section can be measured; the beds are also much slipped and crushed along this side of the bay.

On the north side of Osgodby Nab the Cornbrash again crops out, but there is so much disturbance on both sides of this point that it is impossible to say what beds are really *in situ*. Formerly there was a large mass of the rock which had slipped forward over the fault, and was exposed at ebb tide on the shore below. This seems now to have been entirely removed, and at the time of our survey nothing could be seen of it. Mr. Leckenby informed us that he had obtained *Chemnitzia vittata*, *Acteonina scarburgensis*, *Bulla undulata*, *Pecten demissus*, *Lima rigidula*, *Trigonia*, *Lucina*, *Astarte*, and *Isocardia*, &c. from this isolated portion.

At Wheatcroft the Cornbrash is seen in the top of the cliff, which it follows between the farms of High and Low Wheatcroft. There is about four feet of good solid limestone to be seen at this place resting on the clayey shales of the Estuarine Series, but the rock may be really thicker than this as the upper part is obscured by rubbish. The last exposure of the Cornbrash on the coast is that at Scarborough; where on the north side of the town at the

* There is also a small portion of the rock caught in the fault.

base of the steep cliff formed by the Kellaways Rock it is obscurely seen. This section in former times seems to have been much clearer, for Dr. Wright writing in 1859 says "The rock has here been worked out and will shortly be covered up by the innovations now in progress."* The rock here is from four to five feet in thickness.

Below the drawbridge there is a small portion of the Cornbrash uplifted between the faults, and fragments of the rock may occasionally be found among the grassy slopes; but most of the fossils mentioned from Scarborough have come from the fallen blocks on the shore which have slipped down from this outcrop, and from that to the west.† In fact it is probable that nearly all the fossils enumerated from the Yorkshire Cornbrash have come either from these blocks or from the exposure in Cayton Bay at the foot of Red Cliff.

Owing to the outcrop of the Cornbrash occurring as it does in the midst of shales, and the bed itself being so thin, it is seldom well exposed inland. Along an outcrop extending westwards between 30 and 40 miles there are scarcely half a dozen good exposures of this rock. The best sections are obtained where the Kellaways Rock has weathered out into a vertical cliff as in Lang Dale and Newton Dale; at other places where denudation has not been so great, it is usually covered by débris and soil. The outcrop is however well marked along the flanks of the Tabular Hills by the line of wet ground at the base of the conspicuous feature formed by the Kellaways Rock.

From the point where the Cornbrash is seen in the cliff at Wheatcroft the outcrop turns inland, and rounding the northern end of Olivers Mount may be followed beneath the escarpment of Seamer Moor into the valley of the Derwent.

Along this part of its course there are three small outliers near Falsgrave and Throxenby; besides these there are a few isolated hills just at and north of the former, which, judging from their height, may be capped with Cornbrash, but they are too thickly covered with Drift to be sure about the matter.

In the banks of the stream below Low Langdale End the Cornbrash is well exposed, and the following section was there measured:—

	Ft.	In.
Hard ferruginous limestone with fossils - - - -	2	0
Shaly sandstone - - - - - - -	1	0
Sandstone with root-like markings - - - -	4	0

Further north the fossiliferous portion appears to be rather thicker; and in the upper part of Langdale, where this bed is seen in several places, the measurements are:—

	Ft.	In.
Hard limestone with *Ostrea flabelloides* - - -	3	0
Shaly bed - - - - - - - -	1	0
Sandstone and markings - - - - - -	2	6

* Quart. Jour. Geol. Soc., vol. xvi., p. 26.

† Mr. Bean mentions the rocks below Harlands Cottage as being the best place for collecting. Mag. Nat. Hist., ser. 2, vol. iii., p. 57.

The outcrop of the Cornbrash continues from the south of Hackness along the sides of the Derwent valley, and the branch streams coming down from Troutsdale, Bickley, and Crosscliff. From thence, skirting the sides of the beautiful Langdale gorge, one part turns to the east, and, striking along the hillside above Harwood-dale and Scalby, completes the circuit of the Hackness Hill; the other part, turning west, follows the right bank of the Derwent to High Woof How, near the source of that river, where it attains an elevation of over 900 feet, and thence falls gradually towards Fen Steps into Newton Dale.

In this wild gorge the Cornbrash appears to attain its greatest thickness, and it is certainly a stronger rock and better exposed than anywhere else in Yorkshire. Throughout a large part of this dale the rock forms a small cliff at the base of the great vertical cliffs of the Kellaways Rock. It has a total thickness of from 12 to 14 feet, and is composed of several bands of different lithological character, as will be seen in the following section:—

Section measured in Newton Dale.

	Ft.	In.
Little shale above.		
Cornbrash limestone, very fossiliferous, passing down into limestone with ferruginous bands, which stand out from the rock in nodular lines, over a thin shaly band full of fossils - - - - - - - -	4	6
Sandstone, partly decomposed, with plant-like markings -	3	0
Rubbly grey sandstone, more calcareous than the bed above -	1	0

The outcrop of the Cornbrash, which is very conspicuous in the cliffs of Newton Dale, may be easily traced on either side of the dale from Levisham Station northwards for about five miles to Crag Stone Rigg, where it bends round to the west, and, although not actually seen at the surface, may be easily traced across the moors as far as Stape by the line of wet ground which it forms at the base of the Kellaways Rock. It is here cut through by the little beck running down Raindale, which severs this part of the outcrop from the main mass, so that the beds to the north of the dale are in reality a large outlier.

From Stape the Cornbrash may be traced by Flamborough Rigg, along the southern side of Sutherland Beck, across the valley of the Seven to Lastingham. The bed is well exposed in the beck just north of the village, and also in the next two becks to the west, namely, Loskey Beck and Hutton Beck. The dip about here being rather steep the beds run up between the several small streams in a series of noses or nabs, which give the geological map rather a peculiar appearance.

In crossing the river Dove the bed is not so well seen, but may be followed without much difficulty on the south side of Harland Beck, by Poverty Hill, and above Sleightholmedale Spa, to the Hodge Beck. To the west of this there is a good exposure on the side of a stream on Otterhill Common, but further west there is not much seen of the bed till we reach the River Riccal. Here,

although it is not seen *in situ*, there is a good deal of very fossiliferous limestone in the river below Cowhouse Bank, which belongs to this formation, and has probably slipped from the steep ground above.

Beyond this there are no good exposures of the rock, but its outcrop may be easily traced below Roppa Plantation into Bilsdale, although in this direction the beds seem to be getting thinner, and cannot be followed much further with any certainty.

Besides the great outlying mass of this rock on the west side of Newton Dale, there are several smaller outliers scattered over the Moors to the north, on Harwood-dale Moor, at Blea Rigg, at Simon Howe, near Keldy Castle, and at Trigger Castle; the last of which is interesting both on account of the good exposure the rock makes, and also from the fact of its showing the great roll over there is of the strata about here; the beds at this place dipping rapidly to the north, and being only at the same or a lower level than the main mass at Manley Cross; whereas, allowing for the general southerly dip, they should have been at a considerable greater height.

*There is also an extensive outcrop of the Cornbrash north of the Esk brought on by a great depression of the strata along a synclinal axis ranging nearly parallel with that valley. The outcrop occurs here in numerous outliers fringing the several patches of Kellaways Rock, around which it is always seen when a clear section can be obtained.

In this district there are below the Kellaways Rock ten feet of soft shale, resting on four feet of sandy ferruginous marl. This latter is evidently the residue of the strong ferruginous limestone of the main outcrop, which, from its greater exposure beneath only porous sandstones has been decomposed and converted into soft marl. The best exposure of the rock is on the north side of Hardhill Beck, opposite Green Houses Quarries, where there is the following section:—

	Ft.	In.
Hard sandstone (Kellaways Rock)	—	
Finely laminated shale	10	0
Ferruginous marl	4	0
White shale	5	0
Hard white sandstone	2	0

Besides this there are the following sections of the Cornbrash in this neighbourhood. On the east side of the road from Liverton to Danby, a little south of Elm Ledge Quarry, shales with ferruginous fossiliferous nodules are seen, with a marl bed below; the marl containing *Ostrea flabelloides*, *Terebratula* sp., and an Echinoderm, fragments of the latter occurring at almost all exposures. At the opposite end of Elm Ledge just below the "R" in Danby Low Moor, on the one-inch map, the marl is again seen; on the east side of Danby Beacon, the shale, marl, and the hard white sandstone are all clearly exposed; fragments of the marl also occur along the path on the east side of Brown Rigg.

* The description of this district is taken from Mr. Barrow's account.

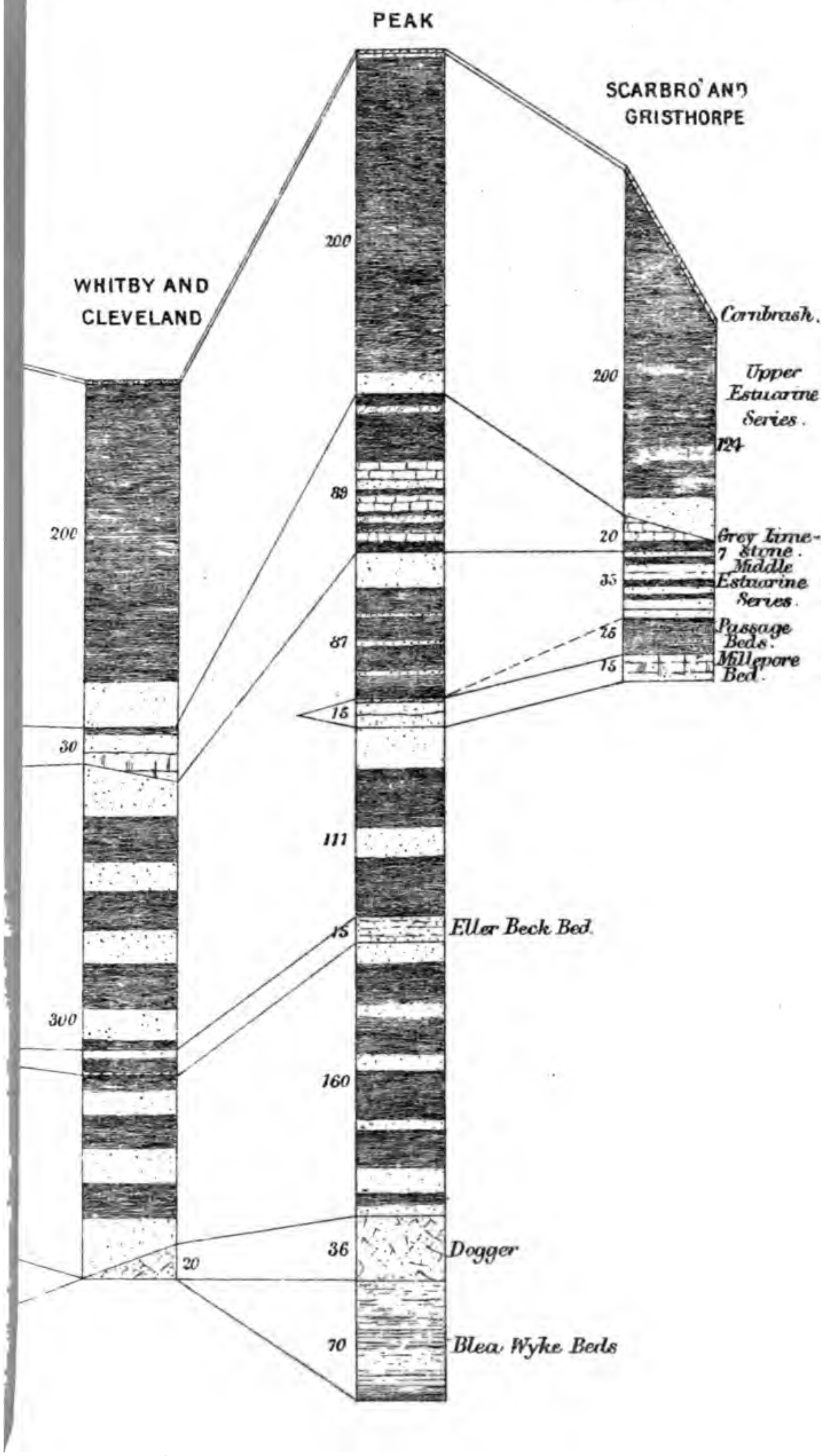
Both the shale and marl are seen about Green Houses, but further east there is too much talus and Drift for any section to occur at this horizon. About Ugthorpe, the base of the Kellaways Rock not being clear, the outcrop of the Cornbrash is doubtful.

Returning again to the main escarpment west of Bilsdale the outcrop of this rock becomes very obscure and we are not aware of a single place where the bed can be seen, although its position is not difficult to indicate along the base of the feature formed by the Kellaways Rock. In this manner it may be traced along the escarpment to Black Hambleton and around the outliers at Hawnby, but we know nothing in this region of either its thickness or character. At Shaken Bridge on the Rye some adits were some time ago made on the line of outcrop, and a little ironstone is said to have been obtained, so that we are justified in supposing that the Cornbrash exists as a solid rock in this neighbourhood. Along the western escarpment the outcrop of this bed is even more doubtful, the only exposure that can be referred to it being in Northwoods Slack, above Boltby Moor, where there is a little grey sandy limestone with *Ostrea*, which may represent this formation. North of this point there is a good line between the Estuarine shales and the sandstone of the Kellaways Rock, although there are no sections exactly on this horizon; but further south the base of the Middle Oolites is not so strongly marked, and in fact coming as it does in the midst of clays, it is impossible to say within a few feet where it should be drawn It would have been very interesting if this bed could have been found below Whitestone Cliff or Roulston Scar, as then we should have had a more certain line for the base of the Oxfordian series and a better junction between the Lower and Middle Oolites than we have been able to draw.

In the Howardian Hills there is no evidence of this formation; this may partly arise from the fact that there are no clear sections exactly on the horizon of it, but it is also evident that the Cornbrash cannot exist as a hard rock, otherwise some fragments of it must have been discovered along the extended outcrop of strata at about this position.

The Cornbrash of Yorkshire does not seem to be of much economic value, although its red ferruginous character has tempted one or two experiments to work it for iron. Besides the attempt at Shaken Bridge, it was also tried several years ago in Newton Dale, but apparently was not thought to be of much value, as the works which are still to be seen in the bank near Skelton Tower were abandoned without the rock being worked to any extent. Mr. Leckenby mentions that in Gristhorpe Cliff the Cornbrash has been occasionally quarried and sent to Hull for conversion into cement.

PLATE IV



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CHAPTER XII.

THE MIDDLE OOLITES.

General Remarks.

The Middle Oolites as they are developed in Yorkshire present a grand series of argillaceous and arenaceous deposits which towards their upper part contain important beds of limestone. The whole of this series forms one natural group in which most of the several divisions pass by insensible gradations from one into another. The complete series consist of the following subdivisions :—

Upper Calcareous Grit.
Upper Limestone and Coral Rag.
Middle Calcareous Grit.
Lower Limestone.
Passage Beds.
Lower Calcareous Grit.
Oxford Clay.
Kellaways Rock.

The series however undergoes considerable modifications in different areas; one or other of these divisions being frequently absent, while some of them occasionally split up into further subdivisions as will be pointed out when we come to treat of the beds in detail.

On glancing at the table of comparative thicknesses it will be noticed that arenaceous deposits prevail in the north, while argillaceous beds are thickest in the south: and if the comparison be carried into South Yorkshire it will be seen that the diminution of the arenaceous strata is even more marked, the whole of the series between the Oxford and Kimeridge Clay having vanished.

These strata, as a whole, occupy an elongated hollow or basin having its longest axis in an east and west direction; around which the several subdivisions crop out in succession on the north, west, and south; the east and south east being cut off by the sea or hidden by the overlap of the Chalk. Along this line of outcrop the Middle Oolites, from their massive character, form three marked ranges of hills encircling the Vale of Pickering:—the Tabular Hills in the north, extending from the Coast to the gorge of the Rye above Helmsley; the Hambleton Hills on the west, overlooking the Vale of York between Northallerton and Thirsk; and the Howardian Hills on the south, extending from Gilling to Malton, and from thence to the foot of the Chalk Wolds in the neighbourhood of Leavening and Acklam.

These hills, around their outer margin, terminate in a bold escarpment, forming a sharp line of demarkation between them and the lower formations at their foot; which is the most

marked physical break throughout the whole series of Oolites. From this escarpment the beds dip towards the Vale of Pickering, the lower subdivisions passing in regular succession beneath the higher ones, which in their turn pass beneath the Kimeridge Clay of the central valley.

Between the north and south of this area important changes take place, which we can only imperfectly follow by tracing their outcrop around the basin. What occurs beneath the Kimeridge Clay in the centre we are at present entirely ignorant; and, until some deep boring has revealed the nature of these rocks, we can only speculate as to whether the same strata are continued below the valley or whether they occur only as a fringing mass around its margin. Mr. Hudleston has suggested that this valley may occupy the place of an old pre-Kimeridgian hollow or lagoon, around which the Corallian beds were deposited:* this may be true, to a certain extent, as far as the Coral Rag with reef-building corals is concerned, but the stratigraphical evidence is certainly against the other rocks occurring in that manner. There can be no doubt that the sudden break between the Middle and Upper Oolite on both sides of the valley, are true faults, which can be traced into older formations; and are not old lines of cliff against which the Kimeridge Clay was deposited.

Palæontologically this series is separable, as pointed out by d'Orbigny and more recently by Hudleston, into the two main groups, Oxfordian and Corallian. The former includes all the beds from the Kellaways to the Lower Limestone, while the latter is formed of the Upper Limestone and its associated beds of Calcareous Grit. The principal change in biological character takes place, as we shall see presently, at the top of the Lower Limestone: below this the fauna is of a distinct Oxfordian type, but above this line it has more affinity with the Coral Rag.

Kellaways Rock.

Origin of the name:—The name of this rock is derived from Kellaways Bridge in Wiltshire, where the peculiar fossils which characterize this sandstone were first observed by W. Smith. The name is variously spelt by different authors: Smith himself called it the "Kelloways Stone," but it has usually been described by subsequent writers under the title of "Kelloway Rock."† Mr. Hudleston suggests that it might be advisable to retain the name "Kelloway" for the Yorkshire rock "as individualizing a formation of greater importance and wider range in time than the bed which so inadequately represents it in Wiltshire"‡; but the Kellaways Rock of the South of England is better known now, and proves to be much thicker than was originally supposed. On the Ordnance Map the locality is called Kellaways, and therefore this mode of spelling is adopted for the rock in question.

* Proc. Geol. Assoc, vol. v., p. 457.

† Prof. Ramsay states that it was originally named "Kelloway's Rock," from Kelloway, who quarried it.—Physical Geology, 5th ed., p. 184.

‡ Geol. Mag. Dec. II., vol. ix., p. 150, note.

Synonyms and Foreign Equivalents:—"Kelloways Stone," Smith, Improved Table to the Map, 1815, and Strata identified by organized fossils, 1816; "Second Shale" (part), "Ironstone and Sandstone" (part), Young and Bird, Geol. Survey of the Yorkshire Coast, pp. 79, 90, 1822; "Kelloway Rock," Vernon, Ann. of Phil., p. 435, 1826; "Kelloways Rock," Phillips, Geol. of Yorkshire, p. 33. 1829; "Hackness or Kelloways Rock," Smith, Geological Map of Hackness, 1832; "Marnes oxfordiennes avec oolithe ferrugineux," Thurmann, Essai sur les soulèvemens, 1832; "Marne moyenne avec minerai de fer oolithique" (lower part), Thirria, Statistique de la Haute Saône, p. 167, 1833; "Walker-Erde," and "Oxford-Thon" (part), Römer, Verst. Ool., p. 7, 1836; "Unterer Oxford-thon u. Kelloway-Rock," Zieten, Correspondenzblatt des württemb. landw. Vereins, 15 Band, p. 5, 42, 1839; "Eisen-oolithe u. Ornatenthone, Brauner Jura ζ" (part), Quenst., Flözgeb., p. 537, 1843; "L'étage kellovien ou Oxfordien inferieur," d'Orbigny, Pal. Française, p. 608, 1844; "Fer oolitique sous-oxfordien ou kellowien," Marcou, Jura salinois, p. 85, 1848; "Fer de l'oxfordien," Mérian, Geogn. Durchscnitt durch das Jura, Denkschr. der schweiz. Gesellschaft, vol. i.; "Oolithe ferrugineux," Mandelsloh, Mém. Soc. d'hist. nat. de Strasbourg, 1835; "Terrains des marnes avec mineral de fer oolithique" (part), Beaudouin, Mém. sur le terrain Kelloway-oxfordien du Chatillonais, Soc. Geol. de Fr., p. 585, 1851; "Le group inférieur ou des argiles de la Woèvre" (part?), Buvignier, Géol. de la Meuse, p. 216, 1852; "Douzième étage: Callovien," d'Orbigny, Cours élément. p. 509, 1852; "Die Schichten des *Ammonites macrocephalus*" (part), and "Die Schichten des *Ammonites ornatus* (Zone des *Amm. anceps* und des *Amm. athleta*)," Oppel, Juraformation, pp. 507, 519, 1856; "Marnes Calloviennes et calcaires marneux," Martin, in Wright, Proc. Cotteswold Nat. Club, p. 145, 1870; "Zone of *Ammonites calloviensis*," Wright, *Ibid.*, p. 213, 1870; "Die macrocephalenschichten" (part), and "Die ornatenthone" (part), Brauns, Die mittlere Jura, pp. 68, 74, 1869; "Kellaways Rock," Geol. Survey Mem. (Expl. of 95 S.W.), 1880.

From the above list of foreign equivalents it will be seen that the Kellaways Rock occupies a position intermediate between the *macrocephalus*-beds and the upper part of the Oxfordian, as these strata are classed on the Continent. In point of fact it appears to include a portion of both these formations, that is the Lower and Middle Oxfordian of other places. Oppel, in his Juraformation, unites the three zones of *Am. macrocephalus*, *Am. anceps* and *Am. athleta* in his Kellaway group; and, although the whole of these distinctions cannot be determined in England, there is no doubt that the Yorkshire Kellaways Rock is capable of division into two well-marked horizons. The lower sandy and shaley beds, although comparatively poor in fossils, nevertheless contain a small number of bivalve mollusca, which have an equal if not greater affinity with the strata below than with those above, and which may be taken as representing to a certain extent the *macrocephalus*-beds of other places; while the upper portion of the rock, which is so enormously rich, especially in ammonites, a large portion of these belonging to the group ornati, undoubtedly represents the ornatenthon of Continental geologists.

How far this latter division should be continued into the Oxford Clay above is a matter of some uncertainty from the great paucity of organic remains in these sandy shales. The Oxford Clay forms a hiatus between the *ornatus*-beds of the Kellaways Rock and the zone of *Am. perarmatus* to which the Calcareous Grit may be assigned. In N.W. Germany the Oxford Clay as a palæontological zone appears to die out, and the ornatenthon is succeeded by the Heersumer Schichten or zone

of *Am. perarmatus*. There is some difference of opinion among foreign geologists as to where the division between the Lower and Middle Oolite should be drawn. Quenstedt and Brauns carry the Brown Jura to the top of the Ornatenthon, whereas Oppel, Von Seebach, and I believe all English geologists, take the line at the top of the Cornbrash, or in the shales above.

The Kellaways Rock is a soft thick-bedded sandstone of a brownish yellow colour; the upper part is on the coast, and occasionally inland, very ferruginous, and forms a hard compact bed of a deep red colour crowded with fossils; below this are softer sandstones or mudstones with but few fossils which gradually pass into sandy shale, and finally into the blueish shale of the Cornbrash clays. In the interior this rock is usually a porous friable sandstone, but its lithological character varies so much both in different localities and in the different beds, which make up the mass of the rock, that it is better to defer a detailed description of the rock till, in tracing its outcrop across the country, we come to the places where it is best exposed.

The following is a catalogue of fossils collected from the Kellaways Rock of Yorkshire, principally by Mr. Leckenby :—

Fossils of the Kellaways Rock.

PLANTÆ.

Cycadaceæ ?
Zamiæ ?

ECHINODERMATA.

Collyrites bicordata, *Leske.*
Astropecten clavæformis, *Wright.*
Astropecten orion, *Forbes.*
—— rectus, *M'Coy.*

CRUSTACEA.

Glyphæa rostrata, *Phil.*
—— scabrosa, *Phil*
Goniochirus cristatus, *Carter.*

BRACHIOPODA.

Discina centralis, *Bean, MS.*
Lingula lævis, *Bean, MS.*
Rhynchonella varians, *Schlot.*
Rhynchonella varians, *Schlot.* var. socialis, *Phil.*
Waldheimia ornithocephala, *Sow.*
—— —— var. umbonella, *Lam.*

LAMELLIBRANCHIATA.

Avicula braamburiensis, *Sow.*
—— clathrata, *Lyc.*
—— expansa, *Phil.*
—— inæquivalvis, *Sow.*
—— ovalis, *Phil.*
Gervillia acuta, *Sow.*
—— aviculoides, *Sow.*
Gryphæa bilobata, *Sow.*
—— dilatata, *Sow.*
Hinnites abjectus, *Phil.*
Lima duplicata, *Sow.*
—— notata, *Goldf.*
—— Phillipsii, *d'Orb.*
Ostrea archetypa, *Phil.*
—— canaliculata, *Bean, MS.*
—— flabelloides, *Lam.*
—— procerula, *Bean, MS.*
—— striata, *Bean, MS.*
—— undosa, *Bean.*
Pecten arcuatus, *Sow.*
—— demissus, *Phil.*
—— fibrosus, *Sow.*
—— inæquicostatus, *Phil.*
—— lens, *Sow.*
—— vagans, *Sow.*
Perna mytiloides, *Lam.*
—— rugosa, *Goldf.*
Pinna mitis, *Phil.*
Placunopsis inæqualis, *Phil.*
Anatina siliqua, *Ag.*
—— versicostata, *Buvig.*
Arca æmula, *Phil.*
Astarte carinata, *Phil.*
—— minima, *Phil.*
—— politula, *Bean.*
—— rhomboidalis, *Phil.*
—— robusta, *Lyc.*
—— ungulata, *Lyc.*

Cardium citrinoideum, *Phil.*
—— cognatum, *Phil.*
—— Crawfordii, *Leck.*
—— striatulum, *Sow.*
—— subdissimile, *d'Orb.*
Corbicella lævis, *Sow.*
—— ovalis, *Phil.*
Cucullæa clathrata, *Leck.*
—— concinna, *Phil.*
—— corallina ?, *Damon.*
—— minima, *Leck.*
Cyprina depressiuscula, *L. & M.*
Goniomya literata, *Sow.*
—— v-scripta, *Sow.*
Gresslya peregrina, *Phil.*
Isocardia clarissima, *Bean.*
—— minima, *Sow.*
—— nitida, *Phil.*
—— tenera, *Sow.*
Leda lachryma, *Sow.*
Lucina Beanii ?, *Lyc.*
—— bellona, *d'Orb.*
—— crassa, *Sow.*
—— lirata, *Phil.*
Modiola bipartita, *Sow.*
—— cuneata, *Sow.*
—— imbricata, *Sow.*
—— Lonsdalei, *L. & M.*
Modiola pulchra, *Phil.*
Myacites æquatus, *Phil.*
—— calceiformis, *Phil.*
—— decussatus, *Bean, MS.*
—— jurassi, *Brong.*
—— modicus, *Bean.*
—— recurvus, *Phil.*
—— securiformis, *Phil.*
Nucula variabilis, *Sow.*
Pholadomya acuticosta, *Sow.*
—— carinata ?, *Goldf.*
—— Murchisoni ?, *Sow.*
—— obsoleta, *Phil.*
—— ovalis, *Sow.*
—— similis ?, *Ag.*
Solemya woodwardiana, *Leck.*
Tancredia curtansata, *Phil.*
Trigonia complanata, *Lyc.*
—— denticulata, *Ag.*
—— elongata, *Sow.* var. lata, *Lyc.*
—— paucicosta, *Lyc.*
—— pullus ?, *Sow.*
—— rupellensis, *d'Orb.*
—— Williamsoni, *Lyc.*
Unicardium depressum, *Phil.*
—— gibbosum, *L. & M.*
—— sulcatum, *Leck.*

SCAPHOPODA.

Dentalium entaloides, *Desl.*

GASTEROPODA.

Actæon retusus, *Phil.*
Alaria bispinosa, *Phil.*
—— —— var. pinguis, *Hud.*
—— trifida, *Phil.*
Amberleya armigera, *Lycett.*
Cerithium abbreviatum, *Leck.*
—— Culleni, *Leck.*
Chemnitzia lineata, *Leck.*
—— vittata ?, *Phil.*
Littorina Phillipsii ?, *L. & M.*
Natica punctura, *Bean.*
Neritopsis, sp.
Patella graphica, *Leck.*
Pleurotomaria depressa, *Phil.*
—— granulata, *Lyc.*
—— guttata, *Phil.*
Purpurina condensata, *Heb. & Desl.*
Turbo sulcostomus, *Phil.*

CEPHALOPODA.

Ammonites alligatus, *Bean.*
—— arduennensis, *d'Orb.*
—— athleta, *Phil.*
—— Bakeriæ ?, *d'Orb.*
—— Baugieri, *d'Orb.*
—— binatus, *Bean.*
—— bipartitus, *Ziet.*
—— biplex, *Sow.*
—— calloviensis, *Sow.*
—— Chamusseti, *d'Orb.*
—— chauvinianus, *d'Orb.*
—— conterminus, *Bean.*
—— convolutus, *Quenst.*
—— crenatus, *Brug.*
—— diversus ? *Phil.*
—— Duncani, *Sow.*
—— flexicostatus, *Phil.*
—— funiferus, *Phil.*
—— glabellus, *Bean.*
—— gowerianus, *Sow.*
—— Gulielmi, *Sow.*
—— hauffianus, *Oppel.*
Ammonites hecticus, *Rein.*
—— —— var. lunula, *Rein.*
—— —— var. putealis, *Bean.*
—— hyperbolicus, *Simp.*
—— Jason, *Rein.*
—— Kœnigi, *Sow.*
—— Lamberti, *Sow.*
—— macrocephalus, *Schlot.* var. rugosus, *Leck.*
—— Mariæ, *d'Orb.*
—— modiolaris, *Luid.*
—— ordinarius, *Bean.*
—— perarmatus, *Sow.*
—— placenta, *Leck.*
—— plicatilis ?, *Sow.*
—— poculum, *Bean.*
—— reversus, *Simp.*
—— turgidus, *Bean, MS.*
Belemnites hastatus, *Montf.*
—— Owenii, *Pratt.*
—— —— var. tornatilis, *Phil.*
Nautilus hexagonus, *Sow.*

PISCES.

Strophodus radiato-punctatus, *Ag.*

The first thing that strikes one on looking at the above list of fossils is the enormous number of cephalopoda. No other formation throughout the whole of the Jurassic period, with the exception of the Lias, and to a certain extent the Kimeridge Clay, has anything like the same abundance. There is no doubt eventually the number of these "species" may be reduced, many of them being probably varieties of better known forms; but, in the meantime, they may be divided into the four main groups, Planulati, Armati, Ornati, and Amalthei or cordate ammonites.* Although 17 species of gasteropoda are enumerated, they are most of them rather rare with the exception of *Alaria bispinosa*, and *Natica punctura*, which, together with *Dentalium elongatum*, are fairly common in a particular band at the top of the formation. The lamellibranchiata are represented by a large number of species, of which the *Trigoniæ* are of particular interest, on account of the great variety which exists between nearly allied species from different localities. Both echinodermata and brachiopoda are scarce, with the exception of *Rhynchonella socialis* which occurs in great profusion.

The Kellaways Rock rises on the shore at Newbiggin Wyke immediately south of the reef formed by the Cornbrash, making a rather more prominent scar than is produced by the thinner bed. The section here is :—

	Ft.	In.
Massive calcareous sandstone, upper part ferruginous and coarsely oolitic - - - - - about	6	0
Soft red sandstone - - - - - -	3	6
Shaly sandstone passing down into grey shaly rock, with white markings containing nests of *Belemnites*, *Modiola*, *Avicula*, and other fossils - - - - - -	2	6
Blue shales.		

In this section the blue shales at the base may be referred to the *Avicula*-shales of the Cornbrash, but it is not quite so certain with what horizon the grey shaly rock above should be classed. It contains curious nests of *Bel. Owenii;* and *Avicula echinata* also occurs in it, so that it really seems to be on the boundary line between the Lower and Middle Oolite, and to constitute a sort of passage from one into the other.

From this point the Kellaways Rock begins to rise in the cliff, and on rounding the Nab we find the following section :—

	Ft.	In.
Soft sandy band - - - - - - -	0	4
Massive sandstone with *Belemnites* and streaks of coaly matter passing down into shales - - - - -	3	6
Shales, *Avicula*, *Mya*, &c. in lower part - - -	11	0
Cornbrash limestone.		

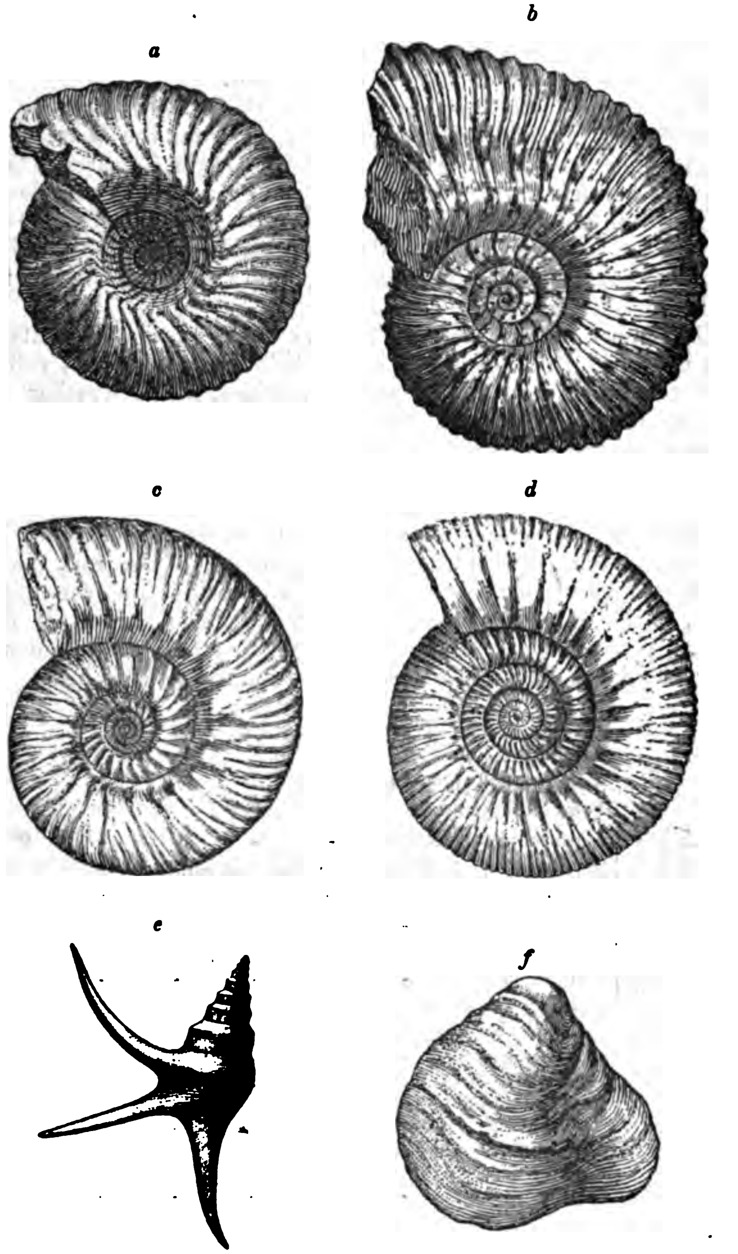
In this section the sandstone is rather thinner than at Newbiggin, but this is principally due to the upper oolitic part dying out; it however rapidly thickens to the westward as will be seen from the next section, which is taken in Gristhorpe Cliff about half a mile further on.

	Ft.	In.
Massive sandstone - - - - - - about	21	0
Soft sands - - - - - - - -	3	0
Shales, including those of the Cornbrash - - -	15	0

* These groups are very clearly explained by Hudleston. Proc. Geol. Assoc., vol. iv., p. 373 et seq.

FIG. 14.

Kellaways Rock Fossils.



a, Ammonites modiolaris, *Luid.* (original) $\frac{2}{3}$; *b*, Ammonites Duncani, *Sow.* (original) $1\frac{1}{2}$; *c*, Ammonites Kœnigi, *Sow.* (original) $\frac{2}{3}$; *d*, Ammonites Bakeriæ, *d'Orb.* (after d'Orbigny) $\frac{1}{2}$; *e*, Alaria trifida, *Phil.* (after Lycett and Morris); *f*, Gryphæa bilobata, *Sow.* (original) $\frac{1}{2}$.

West of this the Kellaways Rock passes beneath the Boulder Clay for a short distance, and when it appears again beyond the fault on the opposite side of the point in Cayton Bay has increased to about 35 feet, but a large part of this is composed of soft sands and shaly beds as will be seen from the section given below, which was measured at the foot of Red Cliff.

This is one of the finest exposures of the Oxfordian series in Yorkshire. The cliff, which rises abruptly from the shore to a height of over 250 feet, is capped by the Lower Calcareous Grit forming a nearly vertical precipice, which graduates in its lower portion into the grey argillaceous beds of the Oxford Clay. These rest on the brownish yellow beds of the Kellaways Rock, which, standing out like a row of buttresses, form the foundation of the cliff.

The upper part of the rock is very ferruginous, and contains the majority of the fossils; the beds below consist of soft yellow sandstone with hard calciferous concretions, which weather out into large rounded masses. These latter, which are less fossiliferous, although they contain a good number of *Avicula*, *Belemnites*, &c., gradually become more shaly, and finally pass down into the dark grey shales of the Cornbrash.

The exposure here is not very easy to measure accurately on account of the frequent slipping of a portion of the rock along joints parallel with the face of the cliff, which repeat the upper beds, so that it is not possible to reach the whole section at one spot. The following section, compiled from two measurements, may be taken as a fairly accurate representation of the beds.

Section of the Kellaways Rock at Red Cliff.

		Ft.	In.
	Shales of the Oxford Clay.		
	Few oolitic nodules.		
All these seem to become one irony rock further west.	Hard band very oolitic	1	0
	Soft shaly rock, like Oxford Clay, but much more calcareous. *Belemnites*	9	0
	Soft sandstone	3	0
	Red irony rock full of *Gryphœa dilatata*. Oolitic in upper part	6	0
	Sandstone soft in places, sometimes very hard and siliceous; weathering into large doggers. *Avicula* in lower part	4	0
	Soft sandstone and hard doggers, few fossils	10	0
	Soft yellow sandstone with *Gryphœa*, &c.	6	0
	Yellow sandy shales	8	0
	Grey shales of the Cornbrash.		
	Total	47	0*

In this section the upper band (1 foot thick) is very oolitic, and being harder than the beds below makes a marked line in the

* The thickness of these lower four beds of soft sandstones and shales appears to be slightly over-estimated. They are about 20 feet when measured in one place.

cliff towards the east end, but towards the west it seems to die out, and the whole upper 19 feet become merged into one brownish red ferruginous rock. The cliff being inaccessible here, it is difficult to see exactly what takes place. Does this band of oolite represent the "calcareous pisolite" mentioned by Leckenby* at the east end of Gristhorpe Bay, but which is now concealed by the large landslip?

Mr. Leckenby divides the upper part of the formation here into two zones, but it is difficult to make out his measurements, and he does not appear to have recognized the oolitic bed at the top. The upper zone, which is a bed of irony sandstone, contains *Am. Kœnigi*, *Am. flexicostatus* and *Belemnites tornatilis*; *Am. flexicostatus* being special to the bed: the lower bed, which is much richer in organic remains, contains besides *Am. Kœnigi* and *Bel. tornatilis*, *Am. modiolaris*, *Am. gowerianus*, *Am. Chamusseti*, *Pholadomya acuticosta*, *Modiola pulchra*, *Gryphæa dilatata*, and *Terebratulæ*.

On the west side of Cayton Bay the Kellaways Rock is thrown down by a second fault, so that it is only obscurely seen along the shore below Tennants Cliff, and against the fault at Osgodby Nab. On the north side of this point there are about 20 feet of soft sandstone, the upper part of which is ferruginous and oolitic, and contains great numbers of *Ammonites*, *Belemnites*, *Gryphæa dilatata*, &c.† At the top of the rock is a thin band of dark coloured calcareous shale, with oolitic grains, which also contains many ammonites including a large tuberculated species. This is probably the calcareous pisolite alluded to above, and if so the bed is not so local as has been imagined, and might be found at other places, if the junction of the Oxford Clay and the Kellaways Rock were better exposed.

From Osgodby Nab the Kellaways Rock rises rather rapidly, but is entirely covered by Boulder Clay till we come to Wheatcroft, where it caps the upper part of the cliff. The lower soft sandy beds are worked here for making the foundations of roads and footpaths, for which this soft rubble seems well adapted. There are about 20 feet of rock seen in the quarry, which consists principally of soft sandstone, with casts of *Avicula braamburiensis*, containing in the lower part large doggers full of *Avicula*, *Pecten*, and a small *Gryphæa*. The upper part of the rock is very irony and slightly oolitic, with masses of shells, *Gryphæa dilatata*, &c. From this point the beds turn inland, and there are no other clear sections along the main outcrop for some distance.

On the outlier at Scarborough the Kellaways Rock is however better exposed than anywhere else in the district. It has here increased to about 75 feet in thickness, and forms the precipitous cliff on the north side of the town. Mr. Hudleston gives the following detailed measurements of the beds in this cliff.‡

* Quart. Journ. Geol. Soc., vol. xv., p. 4.

† This section was well exposed (in October 1885), but was covered up at the time of the original survey, as constantly happens by the slipping of the Boulder Clay.

‡ Proc. Geol. Assoc., vol. iv., p. 304.

Section of the Kellaways Rock at Scarborough.

			Ft.	In.
Brash and Broken Rock; very ferruginous, containing *Belemnites Owenii, Ostrea flabelloides, Gryphæa dilatata*, Ornatus ammonites, &c.			4	0
Upper Tier of Solid Stone. — Subcrystalline fossiliferous rock, with many specimens of ammonites, &c.	1	0	10	0
Rotten irony sandstone with similar fossils	1	6		
Building stone, poor in fossils	7	6		
Loose Muddy Sandstones (thickness estimated)			20	0
Lower Tier of Solid Stone, with *Belemnites Owenii*, &c.			12	0
Loose Clayey Sandstones containing hard bands and doggers with *Astarte* like *A. carinata*, Phil., *Trigonia Rupellensis, Modiola cuneata, Avicula braamburiensis, Pholadomya Murchisoni*, &c.			30	0
			76	0

It is from the upper ferruginous band that most of the fossils have been obtained.* The great mass of the rock below is not nearly so fossiliferous, and although it contains a good number of species in the lower beds it is as Mr. Hudleston points out of a much more estuarine character "and seems to indicate a partial renewal of the physical conditions which had produced the three great Estuarine Series below the Cornbrash."

Below the Castle the Kellaways Rock is seen on the shore at both the north and south angles of the hill, the upper beds being very conveniently situated for examination. The rock where exposed to the force of the sea is very hard, and forms a grand natural protection to the soft shales above. The upper surface of the scar is a hard ferruginous oolite very similar to the other sections along the coast; above this is a thin greyish limestone, with a few oolitic grains containing *Belemnites Owenii*, &c., which we have not noticed elsewhere as a solid rock, but which is very similar to the nodules mentioned at Red Cliff, and the harder fragments in the dark shale at Osgodby.

Turning inland the outcrop of the Kellaways Rock is easily followed by the conspicuous feature it makes along the northern and western flanks of the Tabular Hills. This feature although fairly continuous breaks up into a series of small "nabs" or rounded hills which are very characteristic of its outcrop. This seems to be due to the strong jointing of the rock, together with its tendency to run in calcareo-siliceous masses, which weather out into isolated projections along the inland escarpment; and, along the cliffs of Gristhorpe and Cayton, give rise to the appearance of a line of buttresses or artificial masonry. It is also probable that the absence of these harder masses and the tendency of the rock to become soft unconsolidated sand causes this feature to be occasionally nearly lost and its outcrop difficult to trace.

Although the outcrop of the Kellaways Rock is very clear along the flanks of the hills to the west of Scarborough, there is no particular section where the beds can be measured or studied in

* Mr. Leckenby states that, when the ground was excavated to build the houses along the top of the cliff, many characteristic fossils were found, including examples of *Am. gulielmi* and *Am. gemmatus* of unusual dimensions.

detail. The rock has been quarried at Wheatcroft, Rowbrow Wood, Ayton Forge and Hackness, at all of which places the soft sandy character of the stone, and its tendency to run into doggers, is seen; but the sections are too incomplete to give much idea of the character of the rock throughout its full thickness.

In the Hackness Hill the rock forms a complete outlier, around which its outcrop may be easily followed as well as along the bottom of the interior valleys; but the best section is on the west side in the gorge formed by the river Derwent at Langdale. Here the main mass of the rock which has a considerable thickness forms a craggy cliff on either side of the valley overhanging the soft Estuarine clays below.

In this district the Kellaways Rock is much thicker than it is further south, in fact, there appears to be over 100 feet of sandy rock altogether.

This is chiefly owing to the base of the Oxford Clay above having become more sandy and passing into rock, the combined thickness of the two remaining about the same. Along the northern part of the outcrop of this rock the thickening of the upper portion of the sandstone is very remarkable; for on Blakey Moor, and near the higher part of Langdale, the upper part forms a distinct feature above the general spread of the rock on Lockton, Allerston, and Wykeham High Moors. This upper feature appears to be separated from the main mass of rock below by a thin band of clay, which seems to die out towards the south, but the lines are very obscure, and it is probable that there is a gradual passage from one into the other, as is the case in all the lower subdivisions of the Middle Oolites.

The central portion of the rock is a massive sandstone, graduating into shale both towards the top and towards the base. It is this more massive portion which forms the large spread of moorland to the west of Langdale Rigg. The rock is here very coarse, and the surface of the moor is covered with its large blocks, which give it very much the aspect of a Millstone Grit country.

The great plateau formed by the main mass of the Kellaways Rock is cut through by the gorge of Newton Dale, one of the grandest and most romantic glens in this part of the county; which affords also one of the best sections of the rock to be found anywhere in the interior.

The following section measured near the southern end of Huggitt's Scar gives a good idea of its general character:—

		Ft.	In.
	Massive sandstone	30	0
Fossiliferous band.	Sandstone with fossils	3	0
	Soft sandstone full of fossils	1	0
	Soft sandstone decomposed in places	4	0
	Soft, rubbly sandstone	1	6
	Strong sandstone	2	0
	Shaly, flaggy sandstone	18	0
	Massive sandstone	12	0
	Shaly sandstone and sandy shale	10	0
	Bluish hale	8	0
	Total	89	6

This section does not include the softer beds above, for which another 30 to 50 feet might be added; so that if these are included with the Kellaways Rock, that formation attains its greatest thickness in this region, which is the most northerly outcrop of the upper beds.

On the west side of Newton Dale the Kellaways Rock forms the large outlying mass of Wilden Moor and Wardle Rigg, and thence turns south by Flamborough Rigg, along the foot of the great tabular escarpment to Lastingham. In this neighbourhood there is a steep dip to the south, so that the Kellaways Rock runs up in a series of pointed nabs forming the somewhat remarkable hills known as Askew Rigg, Lastingham Knoll, Spaunton Knoll, and Hutton Knoll, the summits of which are higher than that of the Calcareous Grit escarpment to the south.

West of Farndale the Kellaways Rock skirts round the hill-ends by Poverty Hill, Skiplam Moor, and Roppa into Bilsdale At Coney Birks, in the valley of the Riccal, the rock is very coarse and breaks up into large blocks of grit, one of which was as much as 27 feet in length by 9 feet in breadth.

* On the north side of the valley of the Esk, and from 8 to 12 miles north of the main outcrop, there is a large outlier or rather series of outliers of the Kellaways Rock ranging from Moorsholme Moor through Easington Moor to Ugthorpe. This mass lies on the southern side of a synclinal trough extending in an east and west direction to Whitby, which has brought down the strata along this line, and has been the principal cause of the preservation of an outlier of Kellaways Rock so far north.

Throughout this region the Kellaways Rock is a close-grained sandstone, well-bedded, with lines of quartz pebbles, and forms an exceedingly dry soil. The change in character between this and the ground below is most marked, and considering that the Estuarine shales are the wettest of all the Oolitic strata, it is at once seen how readily this rock may be recognised. On any of these moors it is easy to tell at night when crossing a driftless area of Kellaways Rock, both from the extremely short heather with which it is covered, and the peculiar scrunching of fragments of the sandstone under the feet.

One of the best and most characteristic exposures of the Kellaways Rock occurs in Dimmingdale Quarry, half a mile south of Freebrough Hill. The upper part is here hard and siliceous with small quartz pebbles, but its most striking feature, and one which extends for many miles, is the curious manner in which the rock is absolutely riddled by the hollow casts of *Belemnites*, the whole of which have been dissolved away. Sometimes as many as 50 of these casts occur in a cubic foot of the bed, and blocks of from three to six inches thick will have a dozen cylindrical perforations right through them. This clearly proves that the Kellaways Rock, like many of the other subdivisions of the

* The description of the district north of the Esk is taken from that given by Mr. Barrow.

Lower and Middle Oolites, at some depth below the surface must be a calcareous sandstone, its extreme porous nature being in part due to the dissolution of lime. Along the bedding lines *Pecten demissus*, *Pecten fibrosus*, *Avicula braamburiensis*, *Gryphæa* sp., &c., are very abundant, fragments of *Ammonites* and *Trigoniæ* being not uncommon. The rock is evenly bedded, and much of it makes good hard flags, extensively used for dry-walling and footpaths. Water oozes through the porous grit, and is at once thrown out by the Cornbrash shales, forming a wet line which gives a well-marked base to the rock.

The principal mass of the rock in this region is the great outlier extending from Girrick to Ugthorpe, which on its southern and western side is quite free of Drift and consequently the outcrop is very distinct; but along the north side and about Ugthorpe there is a thick covering of superficial deposits, so that its extent in this direction is not very certain. On the western side of this large outlier close by the sharp bend in the Whitby road where it crosses the outcrop, the Kellaways Rock has been extensively quarried for flags; there are also good sections in Elm Ledge Quarry, and in an opening at the south end of Nean How Ridge. At Green Houses Quarries the upper part is exposed, and is a flaggy marly sandstone, containing a vast number of fossils, similar to those at Dimmingdale, but unfortunately they are mostly casts. The rock is also quarried at High Tranmire and Wood Dale House. On Easington High Moor there is a double line of pits called on the map "Ancient British Settlements.' This term has been applied to many similar holes, for instance, "Killing Pits" on Goathland Moor, the "Pits" above Arnecliffe Wood on the south side of the Esk, and other places; in every instance they occur immediately above a seam of ironstone, and doubtless are nothing but ancient workings for iron ore. The holes on Easington Moor are more or less full of water, and must have been uninhabitable; their position being such that water is constantly oozing through them.

At Ugthorpe Mill the Kellaways Rock is let down by a fault which causes a long tongue of it to run under Ugthorpe as far east as Broom House, where it has been quarried. It here lies in a sharply marked synclinal.

South of the main outlier there are two small patches of the rock, the most easterly of which occurs just south of Ugthorpe, where it is brought in by the fault at Wilks Rigg near Stonegate, but although the sandstone has been quarried the outcrop is not very distinct.

At Danby Beacon there is another small outlier of the Kellaways Rock, which here attains its greatest elevation in this region, 988 feet above sea-level.

On Moorsholme Moor there is a group of outlying patches of this rock which are intersected by several small faults. The most northerly of these are at Oven Close Hill and Smeathorns Hill; at the former of which the Kellaways Rock is brought down by a small fault and has been quarried for dry-walling, only the west

side is free from Drift, but the shape of the ground clearly shows the line of outcrop.

At Smeathorns Hill, south-east of Lockwood Beck Reservoir, there are also several quarries, the ground being partly reclaimed, and the walls built of this sandstone. The fault bounding it on the west is clearly seen and easily followed.

Brown Hill is a small patch of Kellaways Rock cut in two by a small fault. At its south-east end is a quarry in the "Belemnite Rock."

Moorsholme Ridge shows well the dry nature of the ground formed by this bed; but perhaps the most interesting of all the exposures is the small outlier of Freebrough Hill, which consists of Estuarine shales capped by the Kellaways Rock. The following fossils in casts are found in abundance: *Pecten demissus, P. fibrosus, Avicula braamburiensis, Ostrea undosa, Gryphæa* sp., &c. This hill may be seen from a great distance, and meetings of the inhabitants are supposed to have been held here.

A noticeable feature on these moors is the great number of indentations in the outcrop of this bed. As they rarely cut below the Cornbrash, they are usually wet from the constant oozing of the water, and, in consequence, are generally peat-covered; indeed most of the peat in this district occurs in hollows about the base of the Kellaways Rock.

Returning again to the main outcrop, to the west of Bilsdale, the Kellaways Rock forms a conspicuous feature along the flank of the Hambleton Hills, and at the north and south extremities of the remarkable outliers in the neighbourhood of Hawnby; but on the sides of these hills and also about Arden Hall the outcrop is obscured by the heavy landslips of Calcareous Grit brought down by the Estuarine shales below. A long strip of the rock also runs up the valley north of Old Byland, which is exposed at Cadale Mill and other places.

At Black Hambleton the Kellaways Rock attains its greatest elevation, about 1,050 feet above sea level; there is also an outlier of the rock a mile further north on Osmotherley Moor which is at about the same elevation. The rock at this latter place is very fossiliferous in its lower part, and is divided by a shaly band into two portions in a similar manner to what it is where the outcrop reaches the same latitude near Levisham, Saltergate and Langdale End.

The total thickness of the rock at this its north-western extremity is from 60 to 70 feet; it consists of a thick-bedded massive sandstone, partly siliceous and partly sandy, with a ferruginous band towards the top, similar to what the rock has been further to the east, but there are no very clear sections in which to estimate its character or thickness very exactly.

From Black Hambleton the outcrop of the Kellaways Rock turns south, and may be easily followed below the great escarpment of the Calcareous Grit as far as Kepwick, where the talus from the hill above obscures everything.

On Boltby Moor above Cowesby the Kellaways Rock also forms a strong feature, and running out in a long tongue is well exposed in several road sections on that moor. South of this the outcrop is not seen till we get to Heskett Grange, where it is exposed in the road, and there is also a good section below Boltby Scar showing the red ferruginous sandstone with *Ammonites modiolaris*, *Belemnites*, *Ostrea*, &c.

Below Whitestone Cliff, where there is a fine scar exposing these beds, the lower part of the Kellaways Rock is seen to be getting much more shaly, and a bed of clay comes in which we have mapped with the Oxford Clay, and not with the Lower Oolites, as it seems to occupy the same horizon as the sandstones further north, which here appear to be gradually dying out. In the next section we obtain the rock presents quite a different phase.

South of Whitestone Cliff the outcrop is for some distance hidden by landslips, so that it is not possible to follow exactly what takes place; but the next section shows that the thin seam of Oxford Clay above dies out, and that the sandstone of the Calcareous Grit and Kellaways Rock are brought together.

At the base of Roulston Scar there is a peculiar red ferruginous rock crowded with *Gryphæa bilobata* and *Belemnites*, which, although it lies immediately below the Calcareous Grit, must from the fossils it contains belong to the Kellaways Rock. It has a thickness of nearly 50 feet, as will be seen from the following section measured at the base of the scar:—

Section below Roulston Scar.

	Ft.	In.
Vertical cliff of Lower Calcareous Grit, consisting of alternations of hard and soft sandstones with lines of curious forms, resembling fucoids and sponges, much eaten out by exposure to the weather, which has given the beds a very rough and irregular appearance.		
Soft sandstone, very full of *Belemnites*, contains also *Gryphæa*, *Avicula inæquivalvis*, and *Avicula ovalis* - - - -	1	6
Sandstone beds with lines of fossils, *Gryphæa bilobata*, *Belemnites Owenii*, *Placunopsis* - - - - -	5	0
Massive sandstone with *Gryphæa* - - - - -	20	0
Harder bed - - - - - - - - -	9	0
Yellow sandy rock, jointed, becoming softer below - -	8	0
Beds below hidden by talus.		
Total Kellaways Rock seen - - - -	43	6

Following round the outcrop to the east the rock is well seen in the several gullies coming down from the moor, especially in the third one known as Ravens Gill, where the section is—

Section in Ravens Gill.

	Ft.	In.
Limestone - - - - - - - - -	30	0
Red rock containing *Holectypus depressus* and great quantities of *Belemnites*, *Ostrea*, *&c.* - - - - - -	15	0
Massive yellow sandstone - - - - - -	20	0
Total Kellaways Rock - - - - -	35	0

The base is not seen but cannot be far below, as wet clayey ground very soon comes on. The limestone belongs to the measures above, as will be mentioned further on.

Beyond this the rock is not again exposed, till we reach its outcrop in the Howardian Hills to the south of Hovingham, so that there is no evidence as to how far east this peculiar class of rock extends. In Snever Wood and beyond there is a sandy bank below shales, which seems to indicate that the Kellaways Rock is coming on again in its normal character below the Oxford Clay.

Between Wass and Ampleforth the outcrop is completely hidden by talus from the Calcareous Grit, but judging from the country further to the west it is probable that the rock is of no great thickness, and that it occurs merely as a sandy band in the midst of the Oxford Clay.

Again in the faulted trough south of these hills nothing is seen of this bed, although it is evident that if it exists it must crop out below the Boulder Clay in the low ground to the west of Coxwold.

In the Howardian Hills the Kellaways Rock probably first comes in along the steep wooded bank below Gilling Park, but the only indication of the bed is a slightly sandy feature, which occurs some little distance below the base of the Calcareous Grit. Both here and in Hovingham Woods, where the rock must be very thin, its outcrop is masked by the great preponderance of clayey ground both above and below.

East of Hovingham the bed becomes stronger, and is seen cropping out on the side of the projecting knoll just beyond Wath Beck; it is here very siliceous, and stands out from the hill as a large slab; from this point it crops out along the foot of the bank forming a belt of sandy ground which has been denuded into a series of little "nabs" in the same characteristic manner as the Kellaways Rock near the Coast. This sandy feature is well marked on Slingsby Moor, and less distinctly at the foot of Coneysthorpe Banks Wood as far as the fault below Easthorpe Farm; by this fault it is thrown down and crops out again at the foot of Cumbag and Owlers Woods, where it has the same tendency to form little sand hillocks or nabs, which are strikingly shown on the map by the crenulated line representing the base of the rock below Fryton Wood and near Ling Hills.

At the south end of Owlers Wood the beds are cut off by a large fault, so that there is no outcrop of the Kellaways Rock till we get to the neighbourhood of Hutton, a distance of about 3 miles. Close against the fault at East Gaterley Farm there is a small patch of the rock which has been brought against the Kimeridge Clay at this point. It is again seen at Peckondale Barn, where it forms an outlier which is much hidden by Boulder Clay, and in the little valley just north of High Hutton. At this place the beds are depressed by a fault, so that the outcrop is thrown further to the south, and is seen on the south side of the York Road, forming a small sandy nab. From here the rock may be

traced along the lower part of Hutton Banks Wood, and is again seen on the north side of the railway projecting as a small crag at the foot of the hill.*

On the east side of the Derwent the Kellaways Rock is at first cut out by a fault, but shortly appears again near Eddlethorpe Kennels, and may be traced to Fox Cover Plantation, where it stands out as a conspicuous nab of soft sandstone.

South of the Plantation it forms a considerable spread of very sandy land bounded by the large fault at Burythorpe; beyond which it cannot be traced with much certainty, although it is seen at Leavening, where it makes a slight feature, and also at Garrowby.

At Great Givendale, although the rock does not now form a distinct outcrop here, Prof. Blake found nodules bouldered in the Red Chalk full of *Ammonites calloviensis* and *Am. Kœnigi*, showing that the Kellaways Rock originally extended in this neighbourhood, and suffered much denudation during Cretaceous times.†

Throughout the Howardian Hills the Kellaways Rock consists of a bed of soft sandstone with lenticular masses of a harder and more siliceous rock containing a few fossils. These siliceous masses weather out from the surrounding sands, giving rise to the crenulated line of outcrop mentioned above, and at a few places as at Hovingham, Hutton Banks, Fox Cover Plantation, and Leavening to the more prominent nabs, which are so characteristic of this rock. The Kellaways Rock probably has a thickness, in this region, of from 15 to 30 feet; south of Leavening there appears to be even less, but there is no section from which it can be estimated with certainty.

When this rock reappears in South Yorkshire, after an overlap of the Chalk extending for over 13 miles, it still maintains about the same character; so that, although hidden from view, it probably does not undergo much change throughout the intervening ground. Throughout this interval, although there is no absolute exposure of the rock, its outcrop is probably not far off, as evinced by the ammonites that have been found at Givendale, as mentioned above, and which no doubt occur at other places.

When the rock appears again the thickness has increased to as much as from 35 to 40 feet; and, as it is composed of a somewhat harder sandstone, it forms a more important feature than anywhere throughout the Howardian Hills. This thickness is however not maintained for long; and near the Humber, where it entirely loses its distinctive feature, it appears to become considerably less.

* Mr. Hudleston mentions having found *Rhynchonella varians* and a broad *Gryphæa* at this spot. Proc. Geol. Assoc., vol. iii., p. 332; 1874.

† Proc. Geol. Assoc., vol. v., p. 248; 1878.

Throughout this region the Kellaways Rock consists in the upper part of reddish brown sandstones crowded with *Gryphæa* and other fossils, below which are softer beds of sandrock with two lines of large doggers, and at the base soft sands with lines of *Belemnites.*

The Kellaways Rock first appears from beneath the Chalk to the north of Newbald, and in a sand-pit at the village the following section occurs:—

Section in Sand-pit, North Newbald.

	Ft.	In.
Reddish soft sandstone, the lower 2 ft. 2 in. crowded with *Gryphæa bilobata, Rhynchonella, Trigonia* - - -	4	0
Soft whitish sandstone - - - - -	9	0
Thin band, full of casts of *Belemnites,* large and small -		
Soft white sandstone - - - - - -	10	0
Hard band, with *Myacites,* &c. - - - -		

From this pit the beds dip rather sharply (8 degrees) towards the village, where they are obscured by the sand and gravel of the valley, but may be traced with ease to the south, being exposed at several places in the fields to the east of the main road. At a distance of rather more than half a mile south of South Newbald the outcrop crosses the road, but is obscured by a thin covering of Drift as far as Kettlethorpe, where it again crosses the road, and has been worked at an old sand-pit below the farm, and also at Drewton Manor House. At both these places, although the sections have now fallen in, the siliceous doggers are still very apparent.

The best section, however, in the whole district is that exposed in the railway cutting at Drewton, where the beds, which dip at an angle of 3 degrees to the east, are exposed for a distance of over 400 yards, and show the following section:—

Railway Cutting, Drewton.

	Ft.	In.
Dark clay [Oxford] with *Belemnites hastatus,* &c. - -	a few feet.	
Hard brown sandy beds crowded with fossils *Gryphæa bilobata, Avicula braamburiensis, Pinna, Trigonia, Natica, Turbo sulcostomus, Am. Kœnigi, Am. modiolaris, Belemnites* (three species) - - - - - - -	10	0
White and yellow sands with lines of large doggers which weather out from the softer beds - - - -	25	0
Brown sandy band with casts of *Belemnites* in great numbers - - - - - - -	a few inches.	
White sands more argillaceous than those above -	20	0 or more.

Messrs. Keeping and Middlemiss, who give a detailed account of this section,* quote the following list of fossils from the upper brown sandy bed —

* Geol. Mag., 1883.

List of Drewton Kellaways Rock Fossils.

Belemnites Owenii, *Pratt.*
Ammonites modiolaris, *Luid.*
—— Duncani, *Sow.*
—— Kœnigi, *Sow.*
—— gowerianus, *Sow.*
—— Mariæ, *d'Orb.*
Turbo sulcostomus, *Phil.*
—— sp.
Cerithium Culleni, *Leck.*
—— sp.
Alaria bispinosa, *Phil.*
Pleurotomaria.
Gryphæa bilobata, *Sow.*
Pecten demissus, *Phil.*
—— lens, *Sow.*
—— fibrosus ?, *Sow.*
—— (large ribbed species).
Avicula braamburiensis, *Phil.*
—— inæquivalvis, *Sow.*
Perna rugosa, *Goldf.*
Pinna mitis, *Phil.*
Modiola (cylindrical species).
—— pulchra, *Phil.*
Trigonia rupellensis, *d'Orb.*
Cucullæa corallina, *Damon.*
—— sp.
Arca.
Cardium Crawfordii, *Leck.*
—— cognatum, *Phil.*
Isocardia.
Cyprina (2 or 3 species).
Astarte (small ribbed species).
—— ungulata ?, *Lyc.*
Unicardium depressum, *Phil.*
Corbicella ovalis ?, *Phil.*
Pholadomya ovulum ?, *L. & M.* [Ph. ovalis, *Sow.*].
—— Heraulti, *Ag.*
Gresslya peregrina, *Phil.*
Goniomya v-scripta, *Sow.*
Anatina undulata, *Sow.*
Myacites decurtatus, *Phil.*
—— sp.
Rhynchonella socialis, *Phil.*
Waldheimia ornithocephala, *Sow.*

At the cross roads a little to the south of this section 25 feet of red and white sand with balls were passed through in the well at Drewton Stray Cottage,* which represent the lower part of this formation, but the rock is not well exposed between here and South Cave.

At the latter place these beds have been dug for sand, and there is an exposure in a pit at the south end of the village where the sandstone, which contains *Gryphæa bilobata* very abundantly, although soft, is sufficiently consolidated to be worked into small caves.

South of this the outcrop passes under the superficial sand and chalk gravel of the lower ground west of Brantingham, but the rock was met with in the trial-shaft which was sunk for ironstone at the foot of Woo Dale.† We have obtained two accounts of this shaft, and as there is a slight difference between them we give both.

Shaft in Woo Dale: Account supplied by Mr. R. C. Kingston.

	Ft.	In.
Soil	1	0
Gravel	4	0
Clay shale	23	0
Sulphur pyrites	1	0
Gravel and fossils	0	9
Limestone	4	0
Sand and fossils	4	0
Black shale	25	0
Total	62	9

* Page 259.
† Called *Wold Dale* on the one-inch map.

Sinking in Woo Dale: Account supplied by Mr. T. Allison.

	Ft.	In.
Soil and gravel	5	0
Shaley clay	23	9
Iron pyrites	0	9
Limestone	2	0
White sandy shale	4	0
White friable sandstone, water lodges	6	0
Hard grey sandstone, rather micaceous	2	6
Total	44	0

From this shaft it would appear that there are only about 10 feet of Kellaways Rock here, which, if the information is correct, would show that it thins very rapidly in this direction.

South-west of Brantingham Thorpe the Kellaways Rock makes the low sandy mound known as "Sand Hill," but there is so much superficial sand about here that it is difficult to separate one from the other, or to trace its outcrop with much certainty. It probably skirts round the flanks of Mill Hill, west of Elloughton, and thence across the flat to the Humber; but it is entirely hidden in this part of its course by the great thickness of superficial beds.

The projection of the land at Oyster Ness is very likely caused by the outcrop of this bed; but the rock itself, if present, is quite concealed by the mud banks of the Humber.

Oxford Clay.

Origin of the name.—This, which is the old "clunch clay" of William Smith, derives its name from the district where it is largely developed in its passage across the country from Dorsetshire to Yorkshire. In the latter county, however, this formation presents a very different aspect from what it does over the rest of England. It consists of a grey sandy shale, with but few fossils and these badly preserved; which, but for its position between the well-defined sandstones of the Kellaways Rock and Lower Calcareous Grit, could scarcely have been correlated with the dark blue clays of the south. No wonder, therefore, that the earlier geological workers in this county overlooked this bed; and that Smith, Young and Bird, and Sedgwick,* although they evidently expected to find some representative of it at this horizon, failed to recognize in these sandy shales the equivalent of the Oxford Clay of the south. Although Young and Bird, under the name "Second Shale," describe the Oxford Clay, they included too much under this head; and it was left for Prof. Phillips to correctly work out its outcrop on the coast, and its extension inland.

Synonyms and Foreign Equivalents:—"Clunch Clay and Dark Blue Shale," Smith, Memoir to the Map, p. 44, 1815; "Second Shale,"† Young and Bird, Geol. Survey of the Yorkshire Coast, p. 79, 1822; "Great Oxford

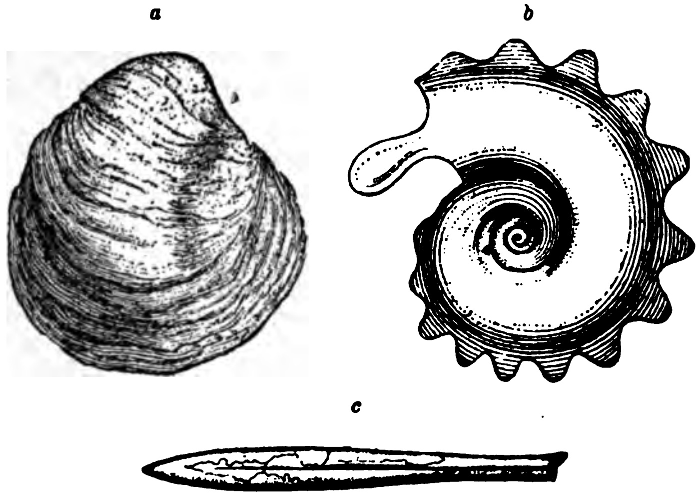
* *See* Chapter I., pp. 9-13.
† Several other formations were erroneously included under this title.

Clay," Conybeare and Phillips, Outlines of the Geology of England and Wales, p. 166, 1822; "Argile de Dives," of Normandy geologists; "Marne argileuse oxfordienne," Brongniart, Tab. des Terrains, p. 410, 1829; "Marne moyenne," Thirria, Carte géol. du départ. de la Haute-Saône, p. 8, Mém. Soc. d'hist. nat. de Strasb., 1830–2, and Statistique de la Haute-Saône, p. 167, 1833; "Oxfordthon" (part), Mandelsloh, Geogn. Profile der schwäb. Alp., t. 3, 1834; "Brauner Jura ζ" (part), Quenst., Flözgeb. Wurt., p. 536, 1843; "L'étage oxfordien," d'Orbigny, Pal. Française, p. 608, 1844; "Marnes oxfordien," Marcou, Jura salinois, p. 86, Soc. Géol. de Fr., 1846; "Des argiles de la Woëvre," Buvignier, Géol. de la Meuse, p. 216, 1852; "Treizième Etage: Oxfordien," d'Orbigny, Cours élément., p. 521, 1852; "Unteres Oxfordien: Die Schichten des *Ammonites biarmatus*," Oppel, Juraformation, p. 616, 1856; "The Zone of *Ammonites Jason*," Wright, Proc. Cotteswold Nat. Club, p. 212, 1870; "Die Heersumer Schichten" (part), Brauns, Der obere Jura, p. 15, 1874.

The Oxford Clay of the south of England has been classed by Dr. Wright and others with the zone of *Am. Jason*, but as it is

FIG. 15.

Oxford Clay Fossils.



a, Gryphæa dilatata, *Sow.* (original) $\frac{1}{4}$; *b*, Ammonites crenatus, *Brug.* after d' Orbigny) $2\frac{3}{8}$; *c*, Belemnites hastatus, *Blain.* (after Phillips) $\frac{1}{8}$.

doubtful whether the usual form of this ammonite* occurs in Yorkshire it is not a good appellation to apply to the formation here. Oppel included it in his zone of *Am. biarmatus;* but this again has the objection that it is a somewhat doubtful, and probably is not an English species, unless it represents a variety of *Am. perarmatus* Therefore taking into account the great paucity of organic remains it certainly appears that it would be more correct to consider the Oxford Clay of Yorkshire either as forming a gap between the *ornatus* zone, and the Calcareous

* *Am. Gulielmi* of the Kellaways Rock is probably *Am. Jason* somewhat modified by the altered nature of its surroundings.

Grit or true zone of *Am. perarmatus*, as suggestde by Hudleston; or include it with the latter zone with which the presence of cordate ammonites in quite the base of the formation would seem to connect it.

With regard to the lithological character of the Oxford Clay there is very little to remark. It is in general a grey sandy shale nearly uniform throughout; which towards the top becomes more sandy, and passes by insensible gradations into the Calcareous Grit above. At the base the junction with the Kellaways Rock is, on the coast, much sharper; but inland, especially towards the north, it is not so well defined, the lower beds also appearing to become more sandy and to inosculate with these sandstones.

There is, as we have said, a great paucity of organic remains throughout the greater part of the formation; and this probably accounts for the fact that there is very little pyrites or selenite, which are so plentiful in the Oxford Clay of the rest of England. The greater part of the fossils, which have been obtained from this formation, have been found in the lower part, in fact only a few feet over the Kellaways Rock; the remainder of these shales is said to be very unfossiliferous, but this may in a measure arise from the exposures being generally not very accessible.* The following list of fossils is mentioned from the Oxford Clay of Yorkshire.

Fossils of the Oxford Clay.

ANNELIDA.

Serpula intestinalis, *Phil.*
Serpula tetragona, *Sow.*

CRUSTACEA.

Glyphæa leptomana, *Phil. MS.*
—— scabrosa, *Phil.*
Mecochirus socialis, *Meyer.*
Pollicipes concinnus, *Morris.*

BRACHIOPODA.

*Rhynchonella varians, *Schlot.* var. socialis, *Phil.*
Waldheimia impressa, *Von Buch.*

LAMELLIBRANCHIATA.

*Avicula clathrata ?, *Lyc.*
—— expansa, *Phil.*
*—— inæquivalvis, *Sow.*
*Gryphæa dilatata, *Sow.*
Lima argillacea, *Lyc. in Phil.*
Pecten articulatus ?, *Schlot.*
*—— demissus, *Phil.*
—— inæquicostatus ?, *Phil.*
*—— vagans, *Sow.*
*Pinna lanceolata, *Sow.*
—— mitis, *Phil.*
Placunopsis inæqualis, *Phil.*
*Astarte carinata, *Phil.*
Astarte ungulata, *Lyc.*
Cardium subdissimile, *d'Orb.*
Corbicella ovalis, *Phil.*
Cucullæa concinna, *Phil.*
* —— pectinata ?, *Phil.*
*Modiola bipartita, *Sow.*
*Myacites recurvus, *Phil.*
Nucula elliptica, *Phil.*
—— nuda, *Y. & B.*
—— turgida, *Bean.*
Pholadomya obsoleta *Phil.*
*—— simplex, *Phil.*

GASTEROPODA.

Alaria trifida, *Phil.*
Amberleya clavata, *Bean.*
Littorina Phillipsii ?, *L. & M.*
Pleurotomaria depressa, *Phil.*
—— granulata, *Lyc.*

* Prof. Williamson gives *Pinna lanceolata* as the only shell in the upper part.

CEPHALOPODA.

Ammonites athleta, *Phil.*	*Ammonites Lamberti, *Sow.*
—— binatus, *Bean.*	*—— Mariæ, *d'Orb.*
—— Comptoni, *Pratt.*	—— oculatus, *Bean.*
*—— convolutus, *Quenst.*	—— perarmatus, *Sow.*
*—— cordatus, *Sow.*	—— Vernoni, *Bean.*
*—— crenatus, *Brug.*	*—— vertebralis, *Sow.*
—— Elizabethæ, *Pratt.*	Belemnites abbreviatus, *Miller.*
—— Eugenii, *Rasp.*	* —— hastatus, *Montf.*
*—— hecticus ?, *Rein.*	*—— Owenii, *Pratt.*

PISCES.

Notidanus serratus, *Fraas.*

One of the best places for collecting is the marly clay just above the Kellaways Rock at the base of the Scarborough Castle Hill, from which place Mr. Hudleston mentions those species marked with a * in the above list.

The fossils from these lower beds contain many species that are common both to the Kellaways Rock and the Lower Calcareous Grit; the presence of *Belemnites Owenii* forms a strong connexion with the beds below, while the cordate ammonites link them with those above. Mr. Hudleston considers that the great mass of barren shales above these more fossiliferous beds may be regarded as the boundary between the Brown and White Jura in Yorkshire, the Oxford Clay being unknown in N.W. Germany, and forming a sort of hiatus between the Ornatus zone and that of *Am. perarmatus.* He says, "For purposes of comparison with N.W. Germany—if it may be deemed proved from negative evidence that the ornati do not occur higher than the top of the Kellaway Rock—we must look upon this great thickness of beds as belonging quite as much to the Upper as to the Middle Jura of that country. The prevalence of the Cordatus family at the base of this Oxford Clay on the Yorkshire coast serves to connect it with the overlying Lower Calcareous Grit through 200 feet of beds, as does the *A. hecticus-lunula* group. On the other hand, the belemnites seem to disconnect it; for we find *B. Owenii* plentiful in the lower part of the Oxford Clay of the Castle Hill, whilst in the Lower Calcareous Grit the stout dagger-like form called *B. excentralis* by Young and Bird, and *B. abbreviatus,* by Miller is the most frequent species. Notwithstanding the thickness of the intervening mass, there seems to be, on the whole, a considerable palæontological connexion between beds so far separated vertically, as the base of the argillaceous series in the Castle Hill and those of the lower part of the Lower Calcareous Grit of Cayton Bay."†

The Oxford Clay first appears on the coast in the cliffs to the north of Filey coming out from beneath the capping of Calcareous Grit. As the beds rise to the north-west it gradually occupies more and more of the lower part of the cliff, till reaching Newbiggin Wyke, where the lower beds begin to appear, it leaves the shore, but continues to rise in the cliffs along Gristhorpe Bay till it passes beneath the Drift at the western end of that bay.

* Proc. Geol. Assoc., vol. iv., p. 380. † *Ibid.*, p. 382.

On the opposite side of the Point, in Cayton Bay, the Oxford Clay again comes out, and the beds being depressed by the fault the Kellaways Rock occupies the base of the cliff. Above this the grey shales of the Oxford Clay, which are here 120 feet thick, form a magnificent sweep beneath the frowning crags of Calcareous Grit which rise to a height of over 250 feet in one of the finest cliffs on the Yorkshire coast. The beds are, however, soon cut off by a second fault at the Pumping Station, and the Oxford Clay is almost entirely hidden by the landslip which obscures this part of the coast.

There is a small exposure of these shales on the north side of Osgodby Nab close against the fault: the beds are here much slipped and broken, but the section is noticeable on account of the Oxford Clay containing veins of calc spar which have not been noticed elsewhere.

From this point the Oxford Clay passes inland; and, excepting the outlier at Scarborough, this is the last that is seen of it on the coast.

At Scarborough the thickness of this formation is about the same as in Cayton Bay, but at the south angle of the hill part of this thickness appears to have been squeezed out in a curious manner; for while the Kellaways Rock is bent up at a rather high angle by the fault, the Calcareous Grit is but little affected, and consequently the thickness between the two increases rapidly in a seaward direction. The Oxford Clay is well exposed in the steep cliffs of the Castle Hill, the base of the formation, as we mentioned above, being very rich in fossils: on the west side of the faults there is a small portion of these shales capping the hill west of the Holmes.

The outcrop of the Oxford Clay inland is easy to distinguish by the slope of wet clayey soil it forms between the steeper banks of the Calcareous Grit and Kellaways Rock. It continues along the face of the great escarpment of the Tabular range from Scarborough westwards, and may be followed around the flanks of the Hackness Hills and up their interior valleys. It is seldom however that the beds are well exposed or that there are sections of any interest.

For this reason it is not easy to make out what takes place at the base of these shales; and to determine whether the thin sandstone, which comes in over the Kellaways Rock, should be classed with that formation; or whether it is merely a sandy band in the Oxford Clay. This bed, as we noticed in tracing the range of the Kellaways Rock, is very conspicuous along the main northern outcrop, being very prominent to the north of Hackness and about Saltergate; from whence it may be traced westwards, with but slight intermissions, to beyond Farndale. Wherever this bed is most prominent it seems to be at the expense of the Oxford Clay, and therefore it probably should be classed with this formation.

The junction of the upper portion of the Oxford Clay with the base of the Calcareous Grit is so gradual that no exact line can

be drawn. The most marked horizon, and perhaps the best on account of the change in soil and the purposes to which the land can be applied, is that where the numerous springs burst forth, and which is also shown by the general wetness of the land below. The Calcareous Grit above this point is also very shaly, and does not become a true sandstone rock for at least another 50 feet or so. These junction-beds are generally well seen in the steep "griffs" which terminate the valleys in this district, and which are kept clear of vegetation by their rapid denudation.

Along the Tabular Hills the outcrop of the Oxford Clay follows the northern escarpment so closely that little detail requires to be given.

The best exposures, besides the sections at the head of the valleys which run into the Calcareous Grit, are at Levisham, Lastingham, Hutton-le-Hole, and a few other places; the rock is also generally exposed where the large moorland streams, which break through the escarpment, cross its outcrop, but these sections are not usually so clear. In the Hole of Horcum, along part of Staindale, and in one or two other deep valleys there are inliers of the Oxford Clay; as well as along the southern side of these hills, in Givendale near Allerston, and in Thornton Dale, where the strata being uplifted by the large fault ranging along the northern edge of the Vale of Pickering, the Calcareous Grit has been cut through and exposed the upper part of this formation.

On the large outlier of the Kellaways Rock north of the Esk there is some ferruginous marl with a shaly top, crowded with fossils, but much decomposed. This, which probably represents the junction with the lowest part of the Oxford Clay, is best exposed near Wapley New Inn.

Returning to the main escarpment, around the northern part of the Hambleton Hills, the Oxford Clay is seldom seen, its outcrop being generally covered by landslips and talus of Calcareous Grit, so that it scarcely ever forms the band of wet ground which it does further east. It is, however, seen on the hillside south of Hawnby and along the Rye, and has been worked near Arden Hall.

Along the great western escarpment these shales decrease in thickness towards the south; at the north extremity below Black Hambleton they are about 50 feet in thickness, which decreases to 30 feet at Whitestone Cliff and at Roulston Scar appears to have died out altogether. The slopes below this lofty inland cliff are so frequently covered by landslips and débris that these are the only clear sections along an outcrop extending for nearly 10 miles; it is therefore not easy to follow what takes place in the intermediate ground.

At Whitestone Cliff 30 feet of shale are exposed between the Calcareous Grit and the Kellaways Rock, but as the lower part of this latter sandstone is also seen to be largely turning into shale it is doubtful whether these basement beds should not be included with the Oxfordian series. In that case we should have an upper and lower division of the Oxford Clay separated by the sandstone of the Kellaways Rock, as suggested by Prof.

Phillips. Whether this lower clay is the equivalent of the "clays of the Cornbrash" may be doubtful, no fossils having been found in it; it appears to be formed at the expense of the Kellaways Rock and therefore to be slightly more recent than the clays below that formation on the coast. The next section at Roulston Scar throws further light on this point, here as we have seen the Calcareous Grit reposes directly on a red ferruginous sandstone, which we take to be the equivalent of the Kellaways Rock of other places; there is no intervening bed of shale, but argillaceous beds come in below, the upper part of which have more the character of Oxfordian shales than of those of the Lower Oolite.

At Wass this red ferruginous rock seems to have disappeared, and the shales of the Oxford Clay come in below the Calcareous Grit in their normal position, there being a section of them up the valley west of the village.

West of this the outcrop is soon cut off by the large fault bounding the Coxwold-Gilling valley at Ampleforth, which has brought in the long strip of Kimeridge Clay filling this hollow; the grit beds which are brought against this formation east of Ampleforth College are some distance above the base of the Calcarous Grit, therefore it is evident that the Oxford Clay cannot crop out here and that the shales seen near the College should be referred to the Kimeridge and not to the Oxfordian strata as has been suggested.

Between these trough-faults shaly beds marking the base of the Calcareous Grit are seen at Wildon Grange and Coxwold, the railway cutting at the latter place being apparently in these shales. It is only however quite the top of the formation that is exposed, and there is no evidence to judge of its thickness or what lies below.

In the Howardian Hills a band of wet ground marks the outcrop of the Oxford Clay in the woods below Gilling Park, in Hovingham High Wood, and along the escarpment to Easthorpe, but there are no sections which call for particular notice. Between Gilling and Hovingham the outcrop is cut out by faults, and there are also one or two slight breaks in it to the south of the latter place. At Wool Knoll the shales have been worked for brick-making but apparently without much success.

At Easthorpe the outcrop is again broken by faults, so that it extends further westwards towards Coneysthorpe and is repeated in the escarpment along the west side of Castle Howard Park. In the bank behind Hildenley Hall there are some shales which from their lithological character are supposed to belong to this formation, but the beds are too much disturbed about here to be sure on the point, and it is quite possible they may represent something much higher in the geological scale.

Between Castle Howard and Hutton the ground is so much broken up that the outcrop between these places is very irregular. It first comes in along the foot of the steep bank immediately east of the house at Castle Howard and may be traced along the slope below the Temple to the Mausoleum.

At Gaterley it is cut out by a fault for some distance, but, coming in again at Nod Hill, is continued as far as High Hutton, where a section is exposed on the side of the York road close to the brow of the hill, from which characteristic fossils are said to have been obtained. At this point the beds are depressed to the south by a large fault, so that the outcrop of the Oxford Clay is thrown forward to Hutton Banks Wood, where it forms the fine escarpment overlooking the Derwent. Judging by the position of the sandstones at the top and near the base of this bank there are about 70 feet of shale here, but this thickness rapidly declines to the south-east; and along the foot of the Wolds between Leavening and Garrowby there is not more than about 20 feet.

Beyond the Derwent the Oxford Clay forms the semicircular bank to the north and east of Eddlethorpe Kennels, and also crops out at Kennythorpe, where it has been dug for marling the sandy land.

East of Burythorpe it again forms a conspicuous bank from Birdsall Grange by Langhill Plantation to Mount Ferrant. At this latter place the outcrop is broken by a line of fault, but is continued again around the village of Leavening.

At Acklam these shales form the lower part of the bank above the village, and a section of them is exposed in the beck below the church. South of this the Oxford Clay forms a wet band at the foot of the Wold as far as Hanging Grimston, when it becomes overlapped by the Chalk, but appears again at Garrowby for a short distance, and has been dug in one or two places. At Menethorpe and Langton there are faulted inliers of this Clay, but they do not call for any particular remark. There is also probably an inlier of the Oxford Clay at Birdsall, but no clay is seen.

In South Yorkshire the Oxford Clay again appears in the railway cutting at Drewton, where the following fossils *Ammonites Comptoni*, *Ammonites Elizabethæ*, *Belemnites hastatus*, *B. Owenii*, *B. abbreviatus*, *Gryphæa dilatata*, *Ostrea gregaria*, and *Pecten*, together with the paddle bone of *Plesiosaurus* have been found in the shales immediately above the Kellaways Rock.

These shales are here far more argillaceous than they are to the north of the Cretaceous overlap, being more like what they are along the outcrop to the south in Lincolnshire and beyond. In fact the resemblance between these shales and the Kimeridge Clay above is so great that except for the undoubted Oxfordian character of the fossils it would be impossible to distinguish them.

In this district also, from the entire disappearance of the Corallian Rocks, it is not possible to say how much of these shales which together have a thickness of over 100 feet should be assigned to the Oxford, and how much to the Kimeridge Clay. It is probable that there is here as in Lincolnshire a complete passage from one into the other; and that, in a general way, the Oxford Clay may be taken as occupying the flatter part of the ground just above the Kellaways Rock, while the Kimeridge Clay forms the steep slopes beneath the Chalk escarpment

CHAPTER XIII.

THE MIDDLE OOLITES (*continued*).

CORALLIAN ROCKS.

THE ZONES OF AMMONITES PERARMATUS AND AMMONITES PLICATILIS.

GENERAL REMARKS.

WE now come to the important group of rocks lying between the Oxford and Kimeridge Clays, which in the Yorkshire area swell out into a grand mass, and form the well-known ranges of hills encircling a great part of the Vale of Pickering. Some comprehensive term is much wanted under which to describe the whole of this series, and perhaps that of "Corallian" as adopted by Messrs. Blake and Hudleston is as good as any other.* Mr. Hudleston has pointed out that this division has no real chronological value, and that it comprises beds of somewhat different age in different parts of Europe; but if we use the term only in a physical sense, as including the great sandbanks and coral reefs which were laid down in the Oxford Kimeridgian sea, there is not this objection. In point of time the whole of this group of rocks contains but two well-marked faunas, the lower part belonging to the Oxfordian, while the upper portion, which includes the Coral Rag, represents to a certain extent the Kimeridgian; consequently under the name Corallian we include a series of rocks overlapping in opposite directions the more important divisions of the Oxford and Kimeridge Clays.

Another difficulty or rather irregularity in the nomenclature of these rocks is the different value given to the term "Coralline Oolite." Some authors we believe include the whole series of Corallian rocks under this name. Prof. Phillips, as he did not divide the Limestone, applied it to that portion of the series lying between the Upper and Lower Calcareous Grit. Mr. Hudleston uses it for the Upper Limestone, or rather for the lower part of that formation exclusive of the Coral Rag. In previous Memoirs explanatory of the maps of this part of Yorkshire we have included both Limestones in the Coralline Oolite, as being fairly descriptive of this class of rock and a suitable name to make use of in those cases where we are unable to separate the lower from the upper division. In this manner we use it in the present Memoir, it being a convenient term to employ when speaking of both Limestones, or where, from the dying out of the intermediate sandstone, we are not sure to which group a particular

* Blake in his later work restricts the term "Corallian" to the upper part of these beds. Quart. Journ. Geol. Soc., vol. xxxvii., p. 497. The same is done by Roberts. *Ibid.*, vol. xliii., p. 229.

bed should be assigned. At the same time we must bear in mind that under either of these names "Corallian" or "Coralline Oolite" we are including a group of rocks of which the upper and lower portion are biologically very distinct. In a general way these two portions may be taken as representing the zones of *Am. perarmatus* and *Am. plicatilis*, the former constituting the upper part of the Oxfordian; while the latter would, according to the larger grouping sometimes adopted, be considered as forming the lower part of the Kimeridgian. The system of nomenclature we adopt is rendered clearer in a tabular form:—

Oxfordian. ? Kimeridgian.	Corallian Rocks.	Coralline Oolite.		
			Upper Calcareous Grit.	Zone of Am. plicatilis.
		Coralline Oolite.	Coral Rag and Upper Limestone.	
			Middle Calcareous Grit.	
			Lower Limestone.	Zone of Am. perarmatus.
			Passage Beds.	
			Lower Calcareous Grit.	

Exception may be taken to this grouping; but we here use the name Kimeridgian only in its larger signification as comprehending all the beds from the true Corallian to the Portlandian inclusive, or those strata to which the term Upper Jurassic is usually applied. Considering the different conditions under which these beds were formed, and the fact that some of the fossils, especially the gasteropoda, extend into the true Kimeridgian, we think it better to emphasize the great change which took place at the top of the Lower Limestone, and which probably represents the dawn of the Kimeridgian era. Thus it is that the Corallian Rocks of Yorkshire can only be correlated with the contemporaneous strata of other parts of Europe on the understanding that they are capable of being united into two groups, which represent distinct periods. The first of these, as may be seen from the table, comprehends the zone of *Am. perarmatus*, under which head we include the Lower Calcareous Grit, the Passage Beds, and the Lower Limestone.

Corallian Rocks.—Part I.

The Zone of Ammonites perarmatus.

Foreign Equivalents:—"Marne argileuse oxfordienne" (part), and "Sable ocreux" of the Calcaire corallique, Brongniart, Tableau des Terrains, pp. viii, 410, 1829; "Oxfordien superieur," Thurmann, Essai sur les soulèvements, 1832; "Argile avec chailles" (part), Thirria, Carte géologique de la Haute-Saône, p. 8, Mém. Soc. d'hist. nat. de Strassb., 1830–2; "Oberer Oxfordthon" (part), von Mendelsloh, Geogn. Profile der Schwäb. Alp, 1834; "Unterer sandiger Coral rag," Römer, Verst. Ool., p. 8, 1836; "Weisser Jura α und β: Wohlgeschichtete Kalkbänke und Spongitenlager," Quenst., Flözgebirge Württembergs, p. 536, 1843; "L'Étage oxfordien" (part), d'Orbigny, Pal. Fr., p. 609, 1844; "Spongitenschichten oder Scyphienkalke," Oppel, Juraformation, p. 646, 1856–8; "Couches d'Argovie ou Argovien," Marcou, Lettres sur les Roches du Jura, p. 163, 1857; "Ox-

fordien: Marnes ferrugineuses oolithiques" (and beds above), Martin, in Wright, Proc. Cottesw. Nat. Club, p. 145, 1870; "Die Heersumer Schichten oder Perarmatenschichten," Brauns, Der obere Jura, p. 15, 1874.

This zone, which for purposes of description we further subdivide, nevertheless contains a well-marked fauna, which unites it into one group, but clearly separates it from the higher zone of *Am. plicatilis*. A careful comparison of this fauna with that from the upper part of the Corallian rocks shows that, although the majority of species pass up from one into the other, still there is a considerable difference between the two groups. Thus many of the species, such as *Rhynchonella Thurmanni*, *Avicula ovalis*, *Gervillia aviculoides*, *Cylindrites elongatus*, *Ammonites cordatus*, *Ammonites perarmatus* and others, which are so plentiful in the lower beds, are either absent or occur but rarely in those above; while several species, that are found sparingly in these beds, are far more abundant, and better developed on the higher horizon. This is especially the case with the gasteropoda, of which a large number of new forms come in, as has been so clearly shown in the admirable account of these rocks by Messrs. Blake and Hudleston.

Further details of this group of rocks are given under the separate sub-divisions.

Fossils of the Upper Oxfordian Series, or Zone of Ammonites perarmatus.

PLANTÆ.

Carpolithes Bucklandi, *L. & H.*
Carpolithes conicus, *L. & H.*

RHIZOPODA.

Rhaxella perforata, *Hinde.*
Stellispongia corallina, *Fromentel.*
Stellispongia glomerata ?, *Quenst.*
—— semicincta ?, *Quenst.*

ACTINOZOA.

Isastræa explanata, *Goldf.*
Rhabdophyllia Phillipsi, *M'Edw.*
Thamnastræa concinna, *Goldf.*
Thecosmilia annularis, *Fleming.*

ECHINODERMATA.

Acrosalenia decorata, *Haime.*
Cidaris Smithii, *Wright.*
Collyrites bicordata, *Leske.*
Echinobrissus dimidiatus, *Phil.*
—— scutatus, *Lam.*
Holectypus depressus, *Leske.*
—— oblongus, *Wright.*
Pseudodiadema versipora, *Phil.*
Pygurus pentagonalis, *Phil.*
Astrogonium, sp.
Astropecten rectus, *M'Coy.*
Millericrinus echinatus, *Schlot.*
Pentacrinus, sp.

ANNELIDA.

Serpula lacerata, *Phil.*
—— squamosa, *Phil.*
Serpula tetragona, *Sow.*
—— tricarinata, *Sow.*

CRUSTACEA.

Glyphæa rostrata, *Phil.*
—— scabrosa, *Phil.*
Glyphæa Udressieri, *Meyer.*

POLYZOA.

Diastopora diluviana, *M'Edw.*

BRACHIOPODA.

Acanthothyris senticosa, var. fileyensis, *Buck. & Walk.*
Rhynchonella lacunosa, *Schlot.*
—— varians, var. socialis, *Phil.*
—— —— var. Thurmanni, *Voltz.*
Terebratula fileyensis, *Walker.*
Thecidium triangulare, *d'Orb.*
Waldheimia bucculenta, *Sow.*
—— ? Hudlestoni, *Walker.*

Lamellibranchiata.

Avicula braamburiensis, *Sow.*
—— expansa, *Phil.*
—— lævis, *B. & H.*
—— ovalis, *Phil.*
Exogyra nana, *Sow.*
—— spiralis ?, *Goldf.*
Gervillia aviculoides, *Sow.*
Gryphæa chamæformis, *Smith.*
—— dilatata, *Sow.*
Hinnites tumidus, *Ziet.*
Lima elliptica, *Whiteaves.*
—— fragilis, *Röm.*
—— gibbosa, *Sow.*
—— læviuscula, *Sow.* var.
—— rudis, *Sow.*
Ostrea flabelloides ?, *Lam.*
—— gregaria, *Sow.*
—— solitaria, *Sow.*
Pecten articulatus, *Schlot.*
—— fibrosus, *Sow.*
—— lens, *Sow.*
—— subfibrosus, *d'Orb.*
—— vagans, *Sow.*
Perna rugosa, *Goldf.*
Pinna lanceolata, *Sow.*
Pteroperna pygmæa, *K. & D.*
Trichites Plottii, *Llhwyd.*
Anatina siliqua, *Ag.*
Arca æmula, *Phil.*
—— astreicola, *Buvig.*
Astarte duboisiana, *d'Orb.*
—— extensa, *Phil.*
Astarte rhomboidalis, *Phil.*
Cucullæa pectinata, *Phil.*
Cypricardia, sp.
Goniomya literata, *Sow.*
—— v-scripta, *Sow.*
Gresslya peregrina, *Phil.*
Homomya gracilis, *Ag.*
Isocardia tenera, *Sow.*
Lucina Beanii, *Lyc.*
—— lirata, *Phil.*
—— obliqua, *Buvig.*
Modiola bipartita, *Sow.*
—— imbricata, *Sow.*
Myacites decurtatus, *Phil.*
—— jurassi, *Brong.*
—— oblatus, *Sow.*
—— recurvus, *Phil.*
Mytilus ? jurensis, *Merian.*
Opis Phillipsi, *Morris.*
Pholadomya angustata, *Sow.*
—— carinata, *Goldf.*
—— cingulata, *Ag.*
—— gracilis ?, *Ag.*
—— paucicosta, *Röm.*
—— simplex, *Phil.*
Sowerbya deshayesea, *Buvig.*
—— triangularis, *Phil.*
Thracia Studeri, *Ag.*
Trigonia Blakei, *Lyc.*
—— clavellata, *Sow.*
—— snaintonensis, *Lyc.*
—— triquetra, *Seebach.*

Scaphopoda.

Dentalium entaloides, *Desl.*

Gasteropoda.

Alaria bispinosa, *Phil.*
Cerithium muricatum, *Sow.*
—— russiense, *d'Orb.*
Chemnitzia heddingtonensis, *Sow.*
Cylindrites elongatus, *Phil.*
Littorina Meriani ?, *Goldf.*
Natica calypso, *d'Orb.* var. tenuis, *Hud.*
Natica punctura, *Bean.*
Nerinæa pseudo-visurgis, *Hud.*
Pleurotomaria bicarinata, *Sow.*
—— cingulata, *Phil.*
—— granulata, *Lyc.*
—— Münsteri, *Röm.*
—— sp.
Pseudomelania Leymeriei, *d'Arch.*
Trochus obsoletus, *Röm.*

Cephalopoda.

Ammonites alligatus, *Bean.*
—— binatus, *Bean.*
—— canaliculatus, *Münst.*
—— cordatus, *Sow.*
—— —— var. excavatus, *Sow.*
—— goliathus, *d'Orb.*
—— hecticus, var. nodosus, *Sow.*
—— perarmatus, *Sow.*
Ammonites sutherlandiæ, *Sow.*
—— varicostatus, *Buckl.*
—— vertebralis, *Sow.*
—— Williamsoni, *Phil.*
Belemnites abbreviatus, *Miller*
—— hastatus, *Montf.*
—— tornalitis, *Phil.*
Nautilus hexagonus, *Sow.*

Pisces.

Asteracanthus ornatissimus, *Ag.*
Hybodus grossiconus, *Ag.*
Hybodus obtusus, *Ag.*
Lepidotus sp.

Reptilia.

Pliosaurus grossouvrei, *Sauvage* (P. teretidens, *Owen, MS.*).

Lower Calcareous Grit.

Zone of Ammonites perarmatus. (Lower part.)

Origin of the name.—All the beds between the Oxford and Kimeridge Clays were originally included by William Smith in the general term "Coral Rag;" but this name is descriptive only of a portion of the series and is inappropriate except for that part which is really composed of this class of rock. Subsequently, in his map of Yorkshire, Smith used the term Calcareous Grit, but as he mistook the Oxford Clay it is not very clear how much he included under this name, the same colour being used for all the strata down to the Lias, although the Calcareous Grit escarpment is shown by a darker shade. Young and Bird described the formation under the name Calcareous Sandstone; while Prof. Phillips adopted that of Calcareous Grit, and determined two horizons of these sandstones to which he gave the names respectively of Lower and Upper Calcareous Grit.

Synonyms:—"Iron sand or Carstone" of the North Yorksh. Moors, Smith, Memoir to the Map, p. 44, 1815; "Sand beneath the Coral Rag and Pisolite," Smith, Strata identified by organised fossils, 1816; "Sand with Rock of Calcareous Grit and Sandstone," Smith, Geol. Map of Yorkshire, 1821; "Calcareous Sand and Grit," Conybeare and Phillips, Outlines of Geology, 1822; "Limestone and Calcareous Sandstone" (part), Young and Bird, Geol. Survey of the Yorksh. Coast, p. 70, 1822; "Lower Calcareous Grit," Phillips, Geol. of the Yorkshire Coast, p. 33, 1829; "The Zone of *Ammonites perarmatus*," Wright, Proc. Cottesw. Nat. Club, p. 213, 1870; "Oxford Grit," Blake, Quart. Journ. Geol. Soc. vol. xxxvii., p. 567.

The petrological character of this rock is that of a yellow calcareous sandstone with doggers and cherty bands passing down into softer sandstones, which become more shaly towards the base and gradually pass into the sandy shales of the Oxford Clay. Although the term "Grit" is applied to this rock there is very little of it that would be called a grit among older formations, in fact many of the sandstones even of the Lower Oolite are harder and firmer and far more gritty than this bed.

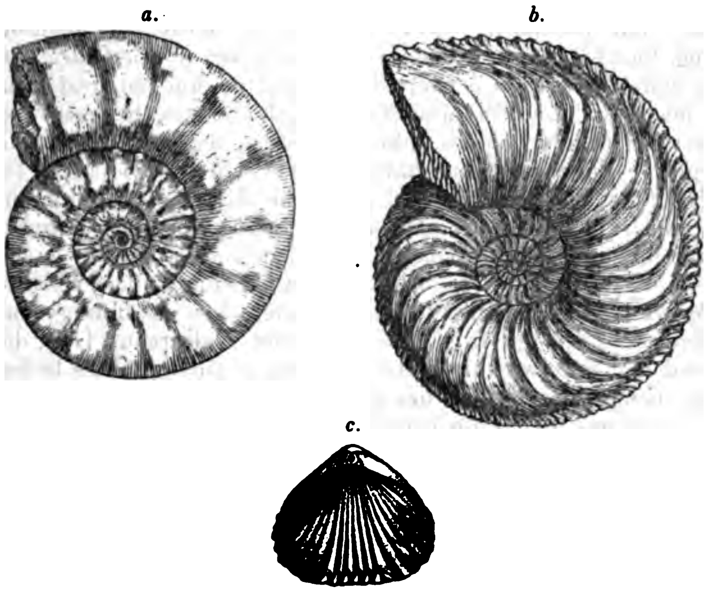
The upper part of the rock is on the coast marked by from 10 to 18 feet of soft sandy beds containing lines of calcareo-siliceous nodules or doggers, which weather out from the softer beds, forming a very conspicuous feature in the cliff sections, and which may be observed at many places inland. These rest on a band of very hard siliceous rock about 3 feet thick, which from its angular mode of weathering forms a marked line in the cliff projecting beyond the softer beds. In the interior this band of rock forms the summits of the Tabular escarpment, where, from the softer sands above being easily denuded away, it covers a large part of the surface giving rise to the great plateaus or table-lands which are so characteristic of these hills.* Below this comes the main mass of the Lower Calcareous Grit composed of rough reddish-yellow grits with siliceous bands and nodules along certain lines;

* *See* Appendix (p. 507). W. Smith, Memoir on the Stratification of Hackness Hills.

which, becoming more argillaceous towards the base, pass by insensible gradations into the Oxford Clay below. The upper part of this portion of the rock weathers into a very rough and irregular surface from the unequal hardness of the sandstone.

FIG. 16.

Fossils of the Lower Calcareous Grit.



a, Ammonites perarmatus, *Sow.* (after d'Orbigny) $\frac{1}{2}$; *b*, Ammonites cordatus, *Sow.* (after d'Orbigny) $\frac{3}{4}$; *c*, Rhynchonella varians, var. Thurmanni, *Voltz.* (after Davidson) $\frac{2}{3}$.

It would appear as if the calcareous and siliceous matter had segregated together along certain lines and spots which standing out from the soft sand produce a lumpy or reticulated appearance. Mr. Hudleston has likened this rock to a fine-grained spongecake.* It is very porous and full of minute cavities which when filled with a white power, probably a silicate, give the rock a speckled appearance. This peculiarity is more marked at some places in the interior, where the specks are much larger than they are on the coast. A weathered fragment from the surface of Rievaulx Moor shows this structure remarkably well; in this specimen the holes which are very minute, are all empty, and nothing remains but a porous mass of siliceous matter, which from exposure has been bleached nearly white. These specks or holes seem to be due to the same cause which produced the ova in the oolite above, and probably mark the commencement of the conditions that produced the limestones. The specimen from Rievaulx Moor has all the appearance of an oolite from

* Proc. Geol. Assoc., vol. iv., p. 384.

which the ova have been dissolved out. Mr. Hudleston suggests that this structure may be due to the fact of the Calcareous Grit being deposited at the same time as oolite beds, formed from the denudation of coral reefs, were being laid down in a neighbouring area.

One curious circumstance connected with the structure of this rock is the fact that it contains numerous minute spheroidal bodies, which give it a very similar appearance to an ordinary oolite. This peculiarity was first noticed by Sorby, who mentions having found reniform bodies in the upper part of the Calcareous Grit, which had been converted into agate; and suggests that they may have been Foraminifera. He also notices the occurrence of certain cellular bodies, like Nodosaria, and also spiculæ of sponge.* Blake mentions having found similar bodies in the Oolite of the South of England, which he also refers to Foraminifera, and for which he proposed the name *Renulina Sorbyana*.†

Subsequently Sollas pointed out that these rounded bodies were more probably of sponge origin, and named them *Geodites Sorbyanus*, Blake.‡ In 1889 Dr. Hinde, when examining some specimens of sponge from the Yorkshire Calcareous Grit, discovered that they were entirely made up of these globate bodies. These sponges to which he has given the name *Rhaxella perforata* "are siliceous, their walls consist of irregularly perforated plates or anastomosing trabeculæ, which are entirely built up of aggregated masses of minute globate spicules similar to those of the recent genera *Placospongia* and *Geodia*, without any apparent intermixture of other spicular forms."§ This is a very interesting fact as it definitely settles that these bodies are not Foraminifera; it also shows from whence they were derived, and the important part played by sponges in the formation of the rock. The mineral composition of the Calcareous Grit, and the causes which produced it, is however a subject well worthy of study; but one which as yet has not been systematically undertaken.

The Lower Calcareous Grit forms the main mass of the range of hills which encircle the Vale of Pickering, around which it crops out roughly in the form of a horseshoe. Starting from the coast at Filey the Lower Calcareous Grit gradually rises in the cliff till turning inland it forms the well-marked feature culminating in the conspicuous hill of Oliver's Mount overlooking the town of Scarborough. West of this it stretches away in a series of bold escarpments by Hackness, Saltergate, Lastingham, and Hawnby to Black Hambleton, where it attains its greatest elevation 1,309 feet above the sea level. At this point the beds curve round towards the south, and the Lower Calcareous Grit caps the grand escarpment of the Hambleton Hills overlooking

* Quart. Journ. Geol. Soc., vol. vii., p. 1.

† Monthly Microscopical Journ.: Trans. Roy. Mic. Soc., vol. xv., p. 262, 1876.

‡ Ann. Mag. Nat. Hist., 5th ser., vol. vi., p. 391, 1880. Hudleston also alludes to a similar structure in the shell-beds of the Coral Rag at North Grimston. Proc. Geol. Assoc., vol. v., p. 443.

§ Quart. Journ. Geol. Soc., 1890, vol. xlvi., p. 59.

the Vale of Mowbray, which rises to an average height of 1,000 feet above the level of the plain. Along the southern end of these hills the beds are sharply cut off by the great fault at Kilburn which has brought down the strata to a much lower level.* South of this dislocation the strata curve round to the east, and the outcrop of the Calcareous Grit ranges through the Howardian Hills from Gilling by Castle Howard and Malton to North Grimston, and thence south by Birdsall and Leavening to Acklam. Throughout this region the Calcareous Grit becomes much thinner and more argillaceous than either to the north or west; the several distinct beds so well seen on the coast cannot be made out, while the lower part of the rock splits up into several bands alternating with sandy shale. The strata, also, being broken up by a large number of faults it ceases to make the fine continuous escarpment that it does to the north and west. The changes however which take place in the rock, both in character and thickness, are best understood by following its outcrop around the basin; which we have shown may in a general way be divided into three areas—the Tabular range on the north, the Hambleton hills on the west, and the Howardian hills on the south. These we will now treat in greater detail.

At the east end of the Tabular range the Lower Calcareous Grit is first exposed in the cliffs north of Filey, where it has a thickness of from 60 to 70 feet. The beds are here very inaccessible except at their eastern end, where the upper part comes above the level of the water, and may be examined on the north side of the Filey promontory. At this spot the upper layers of the rock or ball beds are not far from the level of high-water mark, and consequently are exposed to the full action of the sea. From this cause the cliffs have been cut back into several hollows or "doodles," the floors of which have been worn into miniature baths renewed by every tide, and further excavated by the bombardment they receive from these natural cannon balls. The lower part of these beds forms a small ledge along which it is possible to walk, and here the peculiar nature of the rock may be best noticed. It is seen that the balls have a tendency to run into one another, and form an irregular floor of blue siliceous limestone from which the soft sands have been washed away. The ball beds, which have a thickness of about 10 feet or rather more, form a conspicuous band along the cliff. They rest on a solid band of cherty rock, which, as we have noticed, caps the salients of the great inland escarpment; below this are more sandstones with lines of nodules or doggers which gradually pass down into shaly sandstone. These beds have a thickness of about 50 feet, the lower 14 feet of which consists of the more shaly portion, which latter is very distinct at Gristhorpe and Red Cliff.

From Filey westwards the Lower Calcareous Grit rises in a bold cliff, in which although the beds are inaccessible the three

* On the face of this escarpment the figure of a horse was cut in 1857, which is 180 feet in length, 80 feet in height, and covers 3 roods of ground. W. Grainge, Vale of Mowbray, p. 349.

marked lithological divisions mentioned above may be easily followed by the eye. These three, the soft yellow sands of the ball-beds, the harder and somewhat darker mass of freestones, and the soft shaly sandstone at the base, continue in the cliff as far as the east end of Gristhorpe Bay where the ball beds are lost beneath the Drift, while about the middle of the bay the lower beds also leave the edge of the cliff and pass inland for a short distance. They are soon however brought forward again by the fault at Red Cliff where we have one of the grandest sections on the coast. The Calcareous Grit here rises in a nearly vertical cliff to a height of over 250 feet above the sea, and forms a line of beetling crags which overlook the magnificent sweep of Oxford Clay and Kellaways rock below. The ball beds have been removed from the edge of the cliff, and as there is still about 57 feet of beds above the Oxford Clay, it is evident that these sandstones must be rather thicker in this direction.

On the outlier at Scarborough the Lower Calcareous Grit, exclusive of the Passage Beds, has a thickness of about 60 feet, and is very similar in character to the other sections on the coast. The ball beds and in fact most of the other beds of the Calcareous Grit are easily accessible on the north side of the Castle Hill, where Mr. Hudleston gives the following detailed account of them.* "Below these last beds [*i.e.* the lower part of the Passage Beds] occur 18 feet of loose yellowish grit of medium grain, in which there are two layers of enormous doggers. Some of these contain great masses of shells, which towards the exterior of the ball occur as casts only in an adhering grit devoid of lime; whilst the interior is a mass of such intensely hard blue irony limestone that all the shells are firmly sealed up in it. *Pecten subfibrosus*, *Avicula* sp., *Gryphæa mima*, *Cardium* sp., *Dentalium entaloideum*, &c., young of a cordate ammonite, and a fruit were noticed in one. The 40-inch chert-bed is one of those intensely hard bands which, in the interior, are often used for roadstone. The upper portion weathers in a very honeycomb fashion; the interior is an impure siliceous rock, containing a little calcic carbonate and exhibiting—especially in the lower part—the pore or pinhole structure, to which allusion has previously been made. Much silicified wood occurs in this bed. Next in descending order we have 30 feet of spongiferous (?) calcareous grit, in large blocks, rough enough to roll a Regulus upon. This sub-division may be looked upon as the backbone of the Lower Calcareous Grit proper, and the one which throughout the interior supplies most of the building stones, though not all. It contains the greater proportion of the sponge-cake rock, and the fossils usually occur as casts. . . . . . At Scarborough the fossils are not numerous, though *Pecten subfibrosus* and *Gryphæa mima* still muster comparatively well, as they do throughout the whole vertical section of the Lower Calcareous Grit in this place. Besides these I have noticed *Terebratula fileyensis*, *Pinna* (very plentiful in the beds

* Proc. Geol. Assoc., vol. iv., p. 398.

below), *Gervillia*, *Alaria bispinosa*, and *Pleurotomaria* sp. There is little or no lime on the exterior of the beds, which may be taken as typical Lower Calcareous Grit after long exposure to the atmosphere; colour golden-yellow to buff. The blocks contain, parallel with the bedding, ramose projections which appear like stags' horns, and also, both on the vertical and horizontal face, immense quantities of sponges (?) roughened by small adherent shells. Such blocks strew the beach at the foot of the cliff, and are certain to attract attention from the curious figures which weathering brings out into relief. These peculiarities grow fainter as we descend towards the Oxford Clay; and the formation may be said to commence with about 15 feet of a meagre argillaceous sandstone, which breaks into cuboidal fragments, and shows but few inequalities in weathering."

From Cayton Bay the Lower Calcareous Grit passes inland forming the northern escarpment of the grand range of the Tabular Hills. On Olivers Mount the lower beds, although not the lowest, are quarried for building stone and have yielded the following fossils,—*Avicula braamburiensis*, *Modiola bipartita*, *Trigonia clavellata*, and *Rhynchonella lacunosa*. When the reservoir was made on the summit of this hill the rock was seen to be traversed by a number of open joints which produced large fissures running in a north-west and south east direction.

At Hackness the strata are deeply cut into by the Derwent, which has severed the outlier of Lower Calcareous Grit forming this hill from the main outcrop: this river and its tributaries have produced numerous deep ramifying valleys, the sides of which being frequently wooded are very picturesque. Between these valleys the Calcareous Grit terminates in a series of bold spurs or nabs which have a very striking appearance and a strong resemblance to natural fortresses; in fact, from the remains of dikes and other ancient works which are scattered over their summits, there is very little doubt that they were an important stronghold in former times. In this neighbourhood there is the remarkable outlier of Langdale Rigg which, although nearly two miles in length, is often not more than 50 yards broad at the top. This hill rises to a height of 800 feet at its northern extremity, and has a very peculiar aspect, resembling a truncated cone, when only the end of it is seen as viewed from the north side of Robin Hood's Bay. There are also the curious conical hills at Low Langdale End, and that of Blakey Topping, the summits of which are formed of this rock.

At Saltergate the escarpment of the Lower Calcareous Grit runs out to the north in a long promontory, and forms a large spread of moorland rising to a height of 950 feet above sea-level. From this point the beds decline, and pass by Levisham Moor and Newton to Spaunton, where the summit is not more than about 500 feet above sea-level; beyond this they again rise, and run up in a series of bold headlands between the great intersecting valleys formed by the River Dove, the Hodge Beck, the Riccal and the Seph. Throughout this region the Lower Calcareous

Grit has a thickness of about 150 feet, and consists principally of yellow calcareous sandstone graduating into shale in the lower part, so that no exact line can be drawn between its base and the top of the Oxford Clay. In the upper part the rock becomes very sandy and contains lines of nodules, similar to those seen on the coast, which are well exposed in the bed of the River Seven, about Spaunton and elsewhere. One curious feature connected with the Lower Calcareous Grit in this area are the numerous "griffs" or narrow gullies with vertical sides that the small streams have cut in the lower portion of the rock. These are well seen on Levisham Moor; they are often 30 or 40 feet deep and only a few yards wide, reminding one of miniature cañons.

On the south side of the Tabular Hills at Allerston and Ebberston the Lower Calcareous Grit is brought up by a large fault, so that the whole of these beds, which have a thickness here of about 130 feet, crop out on the hill-side and are worked in several quarries. The following beds are seen in the quarry near the limekilns:—

Section in Allerston Quarry.

	Ft.	In.
Light-coloured and siliceous sandstone with fossils. Lower part nodular - - - - - - -	10	0
Blue siliceous band with fossils - - - - -	1	0
Fine-grained massive sandstone. Worked in large blocks -	15	0

The beds are fairly fossiliferous; and from this quarry and that at the foot of Givendale we obtained *Rhynchonella*, *Avicula braamburiensis*, *Gervillia*, *Ostrea*, *Pecten vagans*, *Astarte*, *Cypricardia*, *Isocardia tenera*, *Ammonites cordatus*, Wood, &c.

West of Bilsdale, where we may be said to enter the Hambleton Hills, the Lower Calcareous Grit becomes harder and more siliceous, and consists principally of cherty sandstone with calcareous bands which being more massive than the beds to the east are able to withstand the action of denudation better, and in a few places as at Peak Scar, Boltby Scar, Whitestone Cliff, and Roulston Scar to form grand vertical cliffs. At the former of these places the following section which shows the siliceous character of the beds was measured:—

Section at Peak Scar.

	Ft.	In.
Oolitic limestone - - - - - - -	12	0
,, weathering sandy - - - - -	2	0
Hard limestone - - - - - - -	3	6
Hard white beds - - - - - - -	6	4
Calcareous beds - - - - - - -	3	0
Hard siliceous bed, dark coloured - - - - -	1	6
Siliceous beds, whitish - - - - - -	7	0
Siliceous calcareous beds, become sandstones further on -	8	5
Cherty sandstones - - - - - - -	53	10
Total thickness exposed - -	97	7

The basement beds, which are softer and more shaly, are not exposed here.

In this neighbourhood the Lower Calcareous Grit forms the main mass of the remarkable outliers of Easterside, Hawnby Hill, and Coum Hill, although their summits are capped by higher beds.

At Black Hambleton where the Calcareous Grit rises to a height of 1,309 feet above sea-level it attains its most north-westerly limit. The rock has here a greater thickness than anywhere else throughout its entire range; judging from the position of the springs which issue from its base there must be nearly 200 feet of sandstone although from the large amount of detritus covering the outcrop it is not easy to calculate it with accuracy.

As we trace the Calcareous Grit southwards along the Hambleton escarpment, we find that it becomes split up by calcareous bands and thin limestones; this is first seen at Boltby, where towards the top of the scar is a thin limestone which appears to be the same as the thick bed to the north at High Paradise and Kepwick, but is certainly not the same as that capping the hill at this spot and dipping eastwards to Cold Kirkby. The following section measured in the scar at Boltby shows this bed, which, however, soon appears to die out and cannot be traced much further to the southward, although there appears to be something of the same sort in the interior valleys:—

Section in Boltby Scar.

		Ft.	In.
Sandstones, 15 ft. 6 in.	Siliceous beds	1	2
	Sandstone, with curious markings	3	2
	Siliceous bed	1	2
	Sandstone	1	4
	"	4	6
	"	1	0
	Siliceous bed	1	4
	"	1	0
	Siliceous sandstone	0	10
Limestone, 16 ft.	Siliceous limestone	1	6
	Sandy limestone	1	6
	Oolitic limestone	13	0
Sandstones, 23 ft. 8 in.	Sandstone	1	6
	Siliceous bed	0	8
	Rubbly bed	1	0
	Sandstone with nodules	2	2
	Siliceous band	1	0
	Sandstone with fucoids	4	6
	Sandstone	0	11
	Massive sandstone with bands of nodules in centre	3	7
	Soft sandstone	1	4
	Sandstone with bands of flint nodules	7	0
	Total beds seen	55	2

Further south this band of limestone dies out, and we obtain one continuous sandstone formation, which forms the grand precipices of Whitestone Cliff and Roulston Scar, where a mural face o over 100 feet is exposed, although this is not quite the full thickness of the rock, some little distance intervening above before the

higher band of limestone comes on. Opposite this latter is the curious conical mass of Hood Hill, which is capped by a small outlier of this rock.

Here the escarpment turns round to the east by Kilburn and Wass to Ampleforth where, from the dying out of the limestone, the sandstones of the Lower and Middle Calcareous Grit come together, and further east can only be treated as one formation.

Beyond Oswaldkirk the Calcareous Grit is cut out for a time, but appears again for a short space about Stonegrave; it is, however, not well seen here, the greater part of the escarpment being formed of limestone repeated by the fault in the bank side. There is a considerable dip to the east along this bank so that it is probable that the dividing line between these sandstones is soon brought against the fault; we should therefore be inclined to refer the sandstone at Oswaldkirk and Stonegrave to the Middle Calcareous Grit, although being very unfossiliferous we have no evidence that such is the case.

In the faulted area about Coxwold the Calcareous Grit is seen in quarries near Wildon Grange, Coxwold, and Newburgh Park; most of these are near the base of the rock, but it does not make a good feature, and its relation to the beds above is obscure.

Throughout the Howardian Hills the strata have been so much disturbed that the outcrop of this rock instead of forming one continuous line across the country is broken up into a series of detached portions having no connexion with one another. In a general way there are two parallel escarpments; the first starts from the picturesque nose of Gilling Park, and ranges by Hovingham Bank and Slingsby Bank to Malton; the second, which is thrown forward by a large east and west fault, commences a little to the west of Castle Howard Park, and ranges through that park by Hutton and Langton to Burythorpe; thence passing south along the edge of the Wolds by Leavening and Acklam till it is lost beneath the overlap of the Chalk. Throughout this area the whole of the sandstone has been considered as belonging to the Lower Calcareous Grit, but whether this is really the case is as yet undecided. It is probable that at Gilling and Hovingham we have both the Middle and Lower Calcareous Grit, while further west towards Appleton the whole of the sandstone that has been mapped appears to belong to the Lower Calcareous Grit.

Along the northern of these two outcrops the Calcareous Grit is traceable from Gilling Park for some distance on either side of the hill to within about a mile of Hovingham Spa. At this point a large fault, which is probably to some extent the cause of these mineral waters, elevates the beds to the south, so that we find the Calcareous Grit capping the hill at Hovingham High Wood, and forming a series of bold escarpments by Bank Wood, South Wood, Fryton Wood, Slingsby Bank Wood, Coneysthorpe Banks Wood to Easthorpe. It is here cut out by the Hildenley faults, but, coming in again at Musley Bank, is traceable as far as Malton, where it is largely quarried for freestone.

At Appleton-le-Street these beds are brought up by a roll of the strata, and are well seen in several quarries near the village. There are about 14 feet of Lower Calcareous Grit seen here beneath the Limestone and Passage Bed, of which Messrs. Blake and Hudleston give the following account: * "The beds visible consist of alternations of soft buff and hard blue rock, which are fairly fossiliferous, especially on approaching the next group. These are the 'freestone' and 'flint' of the workmen. The 'flint' or hard blue, occurs in beds, and sometimes in doggers. The top bed included in this series is pretty full of *Rhynchonella Thurmanni;* it sometimes presents the speckled appearance of the next group. The Ammonites, &c. lie mostly towards the upper part; the following fossils are noted—*Nautilus hexagonus, Ammonites cordatus* (*excavatus*), *A. goliathus, A. plicatilis?* (*A. perarmatus* is less common), *Gryphæa dilatata, Glyphea rostrata,* teeth of *Pliosaurus* and *Lamna?*, Wood. Some of the Brachiopoda quoted in the next series are also met with."†

South of the great east and west fault the Lower Calcareous Grit crops out again at Head Hag and Mill Hill, and also in the western part of Castle Howard Park, where it forms the fine escarpment of Cumhag and Owlers Woods, and dipping to the north-west covers a large area between this point and the Great Lake. There is here a very famous quarry in the grit from which most of the stone was obtained of which Castle Howard is built, and which is also remarkable for the abundance of aptychi of Ammonites and the phragmacones of Belemnites which it contains. From this quarry I was fortunate enough to obtain a specimen of *Ammonites perarmatus* with the aptychus attached. The following species were collected at this quarry :—

Fossils from Park Quarry, Castle Howard.

Collyrites bicordatus.	Ammonites perarmatus.
Holectypus depressus.	—— plicatilis.
Rhynchonella Thurmanni.	—— biplex.
Gryphæa dilatata.	—— cordatus.
Exogyra nana.	Belemnites abbreviatus.
Pecten vagans.	—— hastatus.
Modiola bipartita.	Nautilus hexagonus.

This spread of rock is sharply cut off by an east and west fault ranging just south of Owlers Wood and the Great Lake, which throws up the beds on the south side so that the Calcareous Grit crops out again in Ray Wood immediately east of the house, forming a range of low hills past the Mausoleum to Gaterley. It is here cut out by a great north-west fault, but comes in again at Nod Hill, and may be traced thence nearly to the alluvium of the Derwent. At High Hutton, the beds being depressed by the York Road fault, it forms a considerable spread, and gives rise to

* Quart. Journ. Geol. Soc., vol. xxxiii., p 363.
† *See* page 322.

the finest escarpment, that of Hutton Banks, which the rock makes anywhere in this district.

In the railway cutting here there is a good section of the rock showing the shaly character of the lower part of the formation for a thickness of 16 feet; about 46 feet of sandstones (representing the Calcareous Grit) being shown above.*

The upper part of the rock is very fossiliferous, and the following list has been obtained from quarries in the neighbourhood of the Derwent.

Acrosalenia.	Lima læviuscula.
Collyrites bicordatus.	Lima sp.
Glyphea rostrata.	Ostrea.
Rhynchonella varians, var. Thurmanni.	Pecten vagans.
Anomia	Astarte ovata.
Avicula expansa.	Lucina bellona.
Exogyra nana.	Modiola imbricata ?.
Gryphæa dilatata.	Tancredia.
	Belemnites tornatilis.

Beyond the Derwent, from the faulted nature of the ground, the outcrop of the Lower Calcareous Grit is divided into two tongues, one of which runs to Langton and beyond, appearing again at North Grimston; the other curves round by Eddlethorpe to the conspicuous hill of Fox Cover Plantation, and Kennythorpe; where, meeting with the large Burythorpe faults, it is thrown further to the east, and forms the large spread upon which Birdsall Hall stands. The western edge of this plateau forms a good escarpment, extending from Birdsall Grange by Langhill and Heights Plantations to Mount Ferrant. It is here interrupted by a small fault, but, after a short distance, is continued again by Leavening and Acklam to Hanging Grimston. Between Leavening and Acklam the beds are thrown into a sharp anticlinal, from the summit of which the Lower Calcareous Grit and Oxford Clay were denuded before the deposition of the Chalk; so that, at the axis, that formation reposes directly on the Lower Oolite. This appears also to be the case in the valley from which the Gilder Beck issues, where the Chalk seems to rest directly on the Lias, the whole of the Oolites being cut out; but there is so much talus from the Chalk that the evidence is not very clear. South of Hanging Grimston the Lower Calcareous Grit is hidden by the Cretaceous Beds for some distance, but appears again on the hill above Ley Field near Garrowby, where it seems to have been quarried.

Greystone or Passage Beds.

These beds were formerly included in the upper part of the Lower Calcareous Grit of the coast section, while inland the higher portion of them was classed with the Lower Limestone.

* *See* Geology of the Country N.E. of York and S. of Malton (Geol. Survey), p. 19.

They in reality form a passage from the sandy beds of the Calcareous Grit into the Limestone above, but they have such a peculiar lithological character, and in the country west of Forge Valley make such a distinct physical feature that we have mapped them as a separate division. In this district, where they are locally known by the name of "Greystone," they are extensively quarried for building walls and mending roads. They are also used for the same purposes in the Hackness outlier to the north, where they are better known by the name "Wallstone."

Synonyms:—"Lower Calcareous Grit" (in part), Phillips and others; "Wallstone," Smith, Geol. Map of Hackness, 1832; "Lower Passage Beds," Hudleston, The Yorkshire Oolites, Part II., Proc. Geol. Assoc., vol. iv., p. 396, 1876; "The Greystone or Passage Beds," Mem. of the Geol. Survey (Expl. of 95 S.W.), p. 16, 1880.

In lithological character these beds present every gradation from a sandstone to a limestone; the majority of the rock however consists of highly siliceous limestones, which along certain horizons are very fossiliferous. Inland these beds are more fissile than they are on the coast, and split up into flags often of considerable dimensions. They pass down into a loose sand containing decomposed fragments of the rock, which is evidently its residue, the lime having been dissolved out; on some of the more exposed localities, as Brompton and Troutsdale Moors, there is nothing left but the sand, while the springs which rise from them form large deposits of calcareous tufa in the valley below. The upper part of the rock becomes more calcareous and oolitic as it approaches the true limestone above, the passage being so gradual that no exact line can be drawn between them.

There are fine exposures of these beds on the coast at Filey and Scarborough, at both of which places the whole thickness may be measured and examined in detail. The following section is measured on the north side of the Filey promontory, partly at the east point of the cliff and partly in one of the doodles previously mentioned. In order to show the relation of the beds to one another, we give the whole of the section that is exposed:—

Section measured on the North Side of the Carr Nase, Filey.*

			Ft.	In.
		Boulder Clay resting on a denuded surface.		
Upper Limestone?	Oolitic Limestone.	Irregular rubbly Oolitic Limestone	15	0
		White shelly Limestone partly oolitic, with *Exogyra nana*, *Ostrea duriuscula*, *Pecten articulatus*, *Pecten vagans*	2	0
Middle Calc. Grit?	Filey Brig Calc. Grit.	Fissile slabby beds	3	0
		Massive Sandstone with fucoids on top	2	0
		Shelly band containing *Serpula*, *Gervillia aviculoides*, *Pecten subfibrosus*, *Exogyra nana*, *Gryphæa dilatata*, *Chemnitzia heddingtonensis*	0	7
		Hard massive sandy Grit with *Gervillia aviculoides* and *Pecten subfibrosus* along certain lines	9	0
		Brown and yellow nodular Grit	1	3

* Car-næse. Literal translation "the promontory with the fort."

			Ft.	In.
Passage Beds.	Grey Grits.	Hard grey Grit with irregular top containing *Serpula*, *Vermicularia*, *Avicula*, *Trigonia*	0	6
		Brown and yellow Grit	2	0
		Hard irregular grey Grit	0	8
		Hard grey Grit	1	0
		Nodular bed with comminuted shells	0	10
		Cherty oolitic bed almost pisolitic with fossils *Trichites Plottii*, &c.	0	10
		Oolitic bed with *Serpula*, *Exogyra nana*, &c.	1	3
		Grey gritty bed with small *Serpulæ*	1	10
		Grey gritty bed with *Gryphæa dilatata*, lower and upper valve separate	0	10
		Pale greenish grey Grit	1	0
	Brown and Grey Grits.	Brown sandy bed	2	6
		Grey Grit with *Rhynchonella Thurmanni*	2	6
		Grey Grit with *Rhynchonella Thurmanni*	2	0
		Grey Grit with *Gervillia aviculoides*	1	6
		Brown sandy Grit with *Gryphæa dilatata*	2	9
		Brown sandy Grit with *Pecten subfibrosus*, *Exogyra nana*, *Gervillia aviculoides*	2	6
	Spongy porous Grits.	Rhynchonella bed with fucoidal base containing *Pecten subfibrosus*, *Gervillia aviculoides*	2	6
		Rhynchonella bed, *Rhynchonella Thurmanni* very abundant	1	0
		Spongy bed shaly at base with a band of *Gervillia aviculoides*, *Gryphæa dilatata*	1	6
		Gervillia beds, *Gervillia aviculoides* very abundant	2	0
		Hard grey Grit with *Pecten subfibrosus* and *Gervillia aviculoides*	2	0
		Grey gritty bed full of *Serpula*, *Exogyra nana*, *Pecten subfibrosus*, and Plant remains	1	0
Lower Calcareous Grit.		Soft sandy beds in three or four divisions with very large doggers, *Serpula lacerata*, *Pecten subfibrosus*, *Gryphæa dilatata*, *Exogyra nana*	10	0
		Hard gritty Sandstone with doggers	2	0
		Massive Sandstone passing down into shaly Sandstone about	50	0

The passage beds may be divided into two series—the grey grits and the red or brown grits. At Filey the upper of these divisions consists of grey siliceous and suboolitic limestones alternating with more gritty beds not very rich in fossils. These pass down into brown and grey grit, which are much more fossiliferous, and which are particularly remarkable for the great quantity of Brachiopoda they contain. Towards the base the surfaces of some of the blocks are covered with peculiar branching forms, which may have been dichotomous cylindrical sponges, while the rock itself becomes softer and more porous, and finally passes into the soft sandy beds of the Lower Calcareous Grit. Mr. Hudleston has given such an admirable description of this section that we quote him *in extenso*. "This is an important series of siliceous and sub-oolitic limestones, alternating with yellow calcareous grit; towards the base are shelly grits, and limestones extremely fossiliferous. Some of these latter are remarkable for containing a quantity of Brachiopoda, especially of *Rhynchonella*—a circumstance distinguishing them at once from the Upper Passage-beds. The higher subdivision of this series, from its abundance of grit, has, of course, affinities with the calcareous grit of the Brigg,

whose deposition is foreshadowed by these beds; and we can very easily imagine their becoming so gritty, that we should be disposed to measure them in with the overlying calcareous grit. A line of lenticular nodules, which sometimes coalesce into a hard blue silico-calcareous band, is the topmost bed, and there is generally another of similar character at some little distance beneath. The first eight feet of beds are poor in fossils; still some of the common forms of the Lower Calcareous Grit are scattered about—such as *Gervillia aviculoides*, *Pecten subfibrosus*, &c.; I have found also, *Avicula ovalis*. Below this is a line where there are several small fossils, associated with a small *Serpula*, of rather peculiar form. The lowest ten feet of beds contain a really fine series, and constitute, upon the whole, the most interesting portion of the Filey Brigg section. Some of the beds are peculiar: a specimen, highly charged with *Rhynchonella*, is a blue-centred rather gritty limestone, buff-coloured at the edges, and full of small yellowish oolitic granules, like figseeds, well shown by contrast against the blue matrix. Sections of the stems of *Millericrinus*, in opaque calcite, impart a glistening appearance, which is further enhanced by the sparry condition of some of the rhynchonellas. One little *Pseudodiadema* may be noted. There are plenty of those curious dichotomizing forms in these beds, which throughout the Filey promontory generally are such characteristic features of the Lower Calcareous Grit. Whether these curious forms are due to sponges or not may be a question. It seems probable that they represent an organic body of prolate growth, which ramified freely in the accumulating sandy and calcareous sediment, and whose decomposition has determined the deposit of a larger amount of calcitic and siliceous matter than has been the case with the surrounding mass; weathering has brought this difference into relief. The quantity of organic and pyritous matter yet remaining unoxidised in the cores of these bodies causes them to be blue-centred when the surrounding mass has already assumed the pale buff of the ordinary calcareous grit. Very fine quartzose sand is the principal ingredient of the insoluble portions of these limestones, but there are a considerable number of small oval bodies of opaque white silica, similar to those already mentioned, as occurring in the Upper Passage-beds, where, however, they are generally larger. There is, also, a considerable quantity of opaque white silica in fragments, which seems to have replaced shelly matter.

"Groups and scattered specimens of *Rhynchonella varians*, var. *Thurmanni* are plentiful; more rarely we find a shortish variety of *Terebratula* allied to *T. bisuffarcinata* (*T. fileyensis*, Walker), and there is a small *Waldheimia* occurring rather plentifully upon a certain line. *Gryphæa dilatata*, *Ostrea flabelloides*, *O. solitaria*, *Gervillia aviculoides*, *Isocardia*, *Millericrinus echinatus*, *Serpula*, and nests of the inevitable *Gryphæa minima* are the most obvious fossils. About six feet from the bottom is a bed so full of *Gervillia* as to attract some notice; cordate ammonites occur throughout. *A. perarmatus* is also reported from

here, as we should expect, though probably more plentiful still lower down in the series. I hear also of an ammonite which answers to the description of *A. Williamsoni;* the latter fossil is certainly characteristic of the 'Red beds' of Scarborough Castle Hill, which occupy an analogous place just above the Dogger-series, and are there the representatives, as regards position, of the Lower Passage-beds, though the fauna is somewhat different. Fossil wood is rather plentiful, both in this and the underlying division. These beds are finely exhibited in the curious rocky amphitheatres called 'doodles,' where splendid overhanging slabs of rock belonging to this series may be observed charged with the above fossils, and interwoven with the large dichotomizing branches to which allusion has already been made."*

At Scarborough the division into two series is more marked; the upper beds being characterised by the great quantity of *Gervillia aviculoides* they contain, while the lower beds, which are of a deep brownish red colour, in striking contrast to those above, are much more ferruginous and contain vast quantities of *Exogyra nana* (*Ostrea mima*), *Pecten subfibrosus* as well as a few individuals of other forms.

Section measured on the North Side of the Castle Hill, Scarborough.†

			Ft.	In.
		Boulder Clay.		
Lower Limestone.		Oolitic Limestone in several beds with *Echinobrissus scutatus*, *Exogyra nana*, *Gervillia aviculoides*, and *Trigonia* - - - - - - -	26	6
Passage Beds.	Grey Gervillia Beds.	Falsebedded Grit with small projections weathering black - - - - - - -	4	0
		Soft sandy stone with ferruginous nodules -	1	6
		Parting with *Pecten subfibrosus* - - -	0	8
		Irregular spongy Grit with *Cylindrites* - -	1	0
		Soft bed with uneven base - - -	0	6
		Fine grained grey spongy Grit with *Gervillia aviculoides* - - - - - - -	2	0
		Fine grained hard grey Grit with *Gervillia aviculoides* and *Gryphæa dilatata* - - -	3	0
	Yellow foxy Grits.	Yellow sandy Grit - - - - - -	1	6
		Yellow Grit - - - - - -	3	0
		White Grit passing down into massive spongy Grit with *Gervillia*, *Ostrea*, *Pecten* - - -	5	0
		Yellow Grit with *Gervillia* - - - -	2	0
		Hard band of Grit - - - - -	1	0
		Shaly band with *Pecten subfibrosus*, *Exogyra nana* -	1	0
		Solid bed of Grit - - - - -	2	0
		Six or seven courses of sandy yellow spongy rock with *Rhynchonella*, *Pecten subfibrosus*, *Trigonia*, *Ammonites cordatus* - - - - -	7	0
		Yellow sandy Grit - - - - -	2	6
Lower Calcareous Grit.		Bright yellow soft sands with siliceous balls -	18	0
		Hard massive Grit evenly jointed with a spongy line on top - - - - - -	3	0
		Massive Sandstone passing down into shaly Sandstone.		

* Proc. Geol. Assoc., vol. iv., pp. 403–4.

† *See also* Vertical Sections (Geol. Survey), Sheet 67, No. 4.

Mr. Hudleston in describing this section says:—"They [the upper part of the Gervillia beds] may be easily reached in the angle of the cliff, just under the north battery, where they form a sort of corridor, along which it is possible to creep for a short distance. *Cylindrites elongata*, *Astarte Duboisiana*, d'Orb., *Trigonia perlata?* *Sowerbya triangularis*, two species of myaciform shells, *Rhynchonella Thurmanni* (rarely), *Echinobrissus scutatus*, *Millericrinus echinatus*, *Spongia floriceps*, and the sponge doubtfully referred to *Manon*, have here been observed by me; together with the inevitable *Gryphæa mima* and *Pecten subfibrosus*, which pervade all these beds without distinction, both above and below. . . . The 'Red beds' consist of coarse gritty limestones, largely made up of comminuted shell and sand. They are of moderate thickness and very hard, the surface being much roughened by *Gryphæa mima*, &c. Some of the shells of the upper beds occur, but more sparingly. *Gervillia aviculoides*, for instance, often occurs throughout; but there are swarms of *Pecten subfibrosus* and *Gryphæa mima*, almost to the exclusion of more interesting forms. . . . I have noticed besides these fossils already mentioned, *Belemnites hastatus*, *Ammonites cordatus*, *A. vertebralis*, *A. Williamsoni*, *Lima* near to *L. gibbosa*, Sow., *Echinobrissus scutatus*, also a peculiar variety of *Echinobrissus*, *Millericrinus echinatus*, *Ostrea solitaria*, &c. The principal zone of ammonites seems to be about the base of these Red-beds, and in the doggers of the underlying loose grit. From hereabouts *A. Williamsoni*, *A. Goliathus*, and other cordate ammonites have been obtained."*

These two sections are the only exposures of the Passage Beds along the coast, if we except some slight indications of them just peeping out from beneath the Boulder Clay along the edge of the cliff at Newbiggin. There is little doubt however that they might be followed as a narrow band a little way inland if this covering were removed. Just north of Seamer Station, where the ground is free of Drift, they form a narrow outcrop which by the help of the fragments in the fields may be traced along the slope of the hill to Forge Valley. In this valley there are about 30 feet of these beds, which are well exposed in the steep banks on either side, and in the quarries near Greengate. The beds, which are quarried for roadstone, are very ferruginous and contain great quantities of *Pecten subfibrosus* and *Gervillia aviculoides*.

Messrs. Blake and Hudleston† divide the Passage Beds here into two groups, the lower of which is a thick-bedded ferrugineo-calcareous grit, containing *Lima læviuscula* (peculiar coarsely-ribbed form), *Gervillia aviculoides* (very large), *Pecten fibrosus*, *Rhynchonella Thurmanni*, *Millericrinus echinatus*, &c. The upper is a thin-bedded, impure splintery limestone with occasionally oolitic structure, and contains irregular shell-beds with numerous *Myacites*, along with three very characteristic fossils, viz., *Cylind-*

* *Loc. cit.*, pp. 397–8.
† Quart. Journ. Geol. Soc., vol. xxxiii., p. 321.

rites elongatus, *Gervillia aviculoides*, and *Rhynchonella Thurmanni*.

West of Forge Valley the Passage Beds spread out on the hill-top about Yedmandale and Sawdon, covering large areas of surface, which occupy nearly as much ground as the whole of the limestones above. Over this area an immense number of shallow quarries have been opened in th's stone; in fact, in some parts there is a quarry in almost every field. From the quarries between here and Thornton Dale we obtained *Echinobrissus*, *Rhynchonella lacunosa*, *Terebratula*, *Avicula*, *Lima pectiniformis*, *Ostrea gregaria*, *Pecten subfibrosus*, *Goniomya v-scripta*, *Modiola bipartita*, *Trigonia corallina*, *Belemnites*.

In a quarry at the south end of Wydale there is a very rich shell-bed at the top of this series, from which Mr. Hudleston mentions the following fossils*:—*Diastopora* ? *diluviana*, *Pentacrinus*, sp., *Waldheimia Hudlestoni*, *Arca æmula*, *Astarte* (large), *Astarte extensa*, *Sowerbya Deshayesea*, *Trigonia Blakei*, *T. snaintonensis*, *Trochus inornatus*.

On the Hackness outlier the Passage Beds consist of a hard "glance" limestone, rather ferruginous in places and very fossiliferous, and capable of being split into slabs for building walls and other purposes, for which it is largely used. The lower part of the rock graduates into soft sands, and these again into the more solid sandstone of the Lower Calcareous Grit below.

Further to the west, beyond Bickley, this rock changes very much in character. It becomes much more gritty, and losing the calcareous aspect almost entirely, passes into a true grit, with here and there a few lenticular aggregations of fossils and calcareous bands. It is this rock which forms those remarkable blocks known as Bride Stones; which, standing up on the bleak surface of the moor above Staindale in a most peculiar manner, have a very weird appearance. Besides several masses which join on to the side of the hill, and have more the appearance of ordinary crags, there are about 10 or 12 of these detached blocks, one of which measures as much as 80 feet in circumference and is 16 feet high. About half a mile further west this rock has the appearance of being run together and cemented by silica, and was found to be so hard as to require blasting. It is evidently this siliceous nature which has enabled the Bride Stones to stand out and resist the effects of the weather.

Along the dales to the south this same hard gritty character is very noticeable, and often causes incipient lines of crags to jut out here and there along the sides of the valleys.

At Lockton these beds again become more calcareous, and pass into a hard blue rock which is very full of fossils. Their character is however very variable, and the calcareous matter is readily dissolved out of the rock as was well shown in some sections near here, where all that was left of the calcareous beds were some thin lenticular patches or nodules lying in sand, but which in a short distance would often pass into hard limestone

* Proc. Geol. Assoc., vol. v., p. 481, *et seq.*, Table of Fossils.

These beds are very conspicuous on both sides of Pickering Beck and Levisham Beck; they usually form a hard edge, and in some cases even a line of crags, which is, however, liable to crumble away from the tendency of the rock to decompose and turn into sand, causing a great deal of the land along its outcrop to be of a very sandy nature.

The outcrop continues as a thin sandy band by Newton to Cropton, where it is quarried at several places, and is well seen on the side of the road going down to Rosedale. The entire succession is here very clear, and the section may be followed almost uninterruptedly from the ball beds of the Lower Calcareous Grit through the Passage Beds and Lower Limestone to the base of the Middle Calcareous Grit. In this region the Passage Beds are not so ferruginous as they are near the coast and, as Mr. Hudleston mentions, are remarkable for large specimens of *Gervillia aviculoides.*

On the other side of the valley these beds are continued by Hamley to Spaunton, just beyond which they are depressed by a fault throwing the outcrop to the north, so that they appear at the edge of the escarpment at Riccal Head, and form the fine tabular hills on either side of Hutton-le-Hole. At Gillamoor the Passage Beds are still recognizable, and quarries are opened out in them, but the boundary lines dividing them from the Calcareous Grit below and the limestone above are becoming very uncertain; further west they cannot be separated.

Beyond this they appear to become merged in the great mass of siliceous strata which set in at the top of the Lower Calcareous Grit, and pass up into the limestone.

When the Upper Limestone and Middle Calcareous Grit come up again on the south side of the synclinal at Ampleforth and Oswaldkirk these beds and the limestone above have disappeared; and, although a few feet of "passage beds" occur beneath the Upper Limestone, they are at a higher horizon, and will be mentioned when treating of that bed.

The same thing occurs throughout the Howardian Hills on the opposite side of the valley from Gilling to Malton, and from Castle Howard to North Grimston, where oolitic gritty beds occur at the base of the Limestone constituting a sort of passage between it and the Calcareous Grit below. These should probably in part be correlated with the Passage Beds mentioned above, although they can scarcely be said to be identical in all cases. They are not more than a few feet in thickness, and are composed of calcareous grits and sandy limestones with oolitic grains; they contain the following characteristic fossils, *Pecten fibrosus, Avicula ovalis, Rhynchonella Thurmanni, Echinobrissus scutatus,* and *Millericrinus echinatus.* These beds are seen at the base of the limestone wherever a fairly good section occurs; but on account of their extreme thinness, and the outcrop being frequently in a steep bank, they have not been shown by a distinct colour on the map. At the western end of their outcrop about Gilling these beds appear to correspond in position with those on the opposite site of the valley at Ampleforth and Oswaldkirk, that is at

the base of the Upper Limestone, and above the Middle Calcareous Grit, but when we get to the eastern end of their outcrop, about Appleton-le-Street, and Malton, they appear to lie at a lower horizon, and certainly occur at the top of the Lower Calcareous Grit; whether this apparent discrepancy is owing to the thinning out of the beds in the intermediate area, or to the difficulty in tracing the lines across the faulted area on the hill top south of Slingsby, there is not sufficient evidence to say.

These beds are quarried at Appleton-le-Street and Malton where good sections are exposed; these are described in considerable detail by Messrs. Blake and Hudleston, who therefore we quote:—"Sandy-speckled limestones of considerable hardness, varying from buff to blue, and constituting a stone difficult to describe, but easily recognized. These are beds intermediate between the Lower Calcareous Grit and the oolites, and represent, to a certain extent, the passage-beds of the Tabular range. They are somewhat irregularly developed, and vary in different quarries. The fauna is much the same as the top bed of calc-grit, but richer both in individuals and species. In addition to some of the Ammonites already quoted [*A. cordatus, A. goliathus, A. plicatilis* ?] the following may be deemed characteristic:—

Pecten fibrosus.
Avicula ovalis.
—— expansa.
Trigonia, sp. n.
Waldheimia bucculenta.
Terebratula fileyensis.
Rhynchonella varians, var. Thurmanni.
Glyphæa rostrata.
—— scabrosa.
Echinobrissus scutatus.
Millericrinus echinatus.

The association of Brachiopoda strongly reminds us of the fossiliferous group a few feet above the ball-beds at Filey; *Millericrinus echinatus*, essentially a lower passage-bed form, is also abundant in both. There is moreover a strong lithological resemblance in the peculiar speckled character of the stone. Altogether this is the best exposure obtained in the Howardian Hills of a fossiliferous phase of the junction-beds between the Lower Calcareous Grit and the oolites (Corallian Limestones). They differ much from the ordinary type of passage-beds (the flaggy ferruginous calc-grits) of the Tabular Hills."*

"If we again seek a section showing these passage-beds into the oolites above, such a junction may be observed, as at Appleton, in the Brows Quarry, situated in the western suburb of Malton.

Section in the Brows Quarry, Malton.

			Ft.	In.
A.	*a.*	Buff-coloured, gritty, suboolitic limestones and brash	6	0
	b.	Bed occasionally containing much fine-grained calc-grit	2	0
	c.	Buff-coloured gritty limestones, with a very few straw-coloured granules, in thick beds with thin brashy partings	12	0
C.	*d.*	Calc-grits, *i.e.* freestones, alternating with blue stone: *Ammonites plicatilis* in the upper part, *Glyphæa rostrata, Gryphæa dilatata*, wood, &c.,—not very fossiliferous	27	0
			47	0

* Quart. Journ. Geol. Soc., vol. xxxiii., p. 368.

"The contrast between this exposure and that at Appleton shows how much is due, even on the same horizon, to the accidents of distribution. The Brachiopoda are entirely absent (to the best of our knowledge) in *c*, and the upper part of *d; c* in this section occupies the position of the very fossiliferous passage-beds of Appleton ; but there is no very marked difference in any of the beds forming the group A of the quarry. The fossils noticed are *Am. plicatilis* (interior whorls), *Am. cordatus, Pecten fibrosus, Avicula ovalis, Pleuromya*, sp., and *Echinobrissus scutatus*."*

On the south side of the great Coneysthorpe fault these beds come on again, and are well exposed along the road east of the village; there are also small patches of the rock close against the faults at the Mausoleum, Gaterley, Nod Hill, and Hutton.

East of the Derwent there is a considerable spread of these beds along the terrace just north of Langton village. They have a thickness of about 15 feet, and are composed of hardish siliceous grits with oolitic grains, which give them a speckled appearance. Although of no very great extent, the outcrop of these beds, on account of their harder nature, covers a larger area, and the rock has been more frequently quarried than anywhore else on this side of the Vale of Pickering. They are also seen on the south side of the beck near Menethorpe, and again at Kennythorpe; but beyond the large faults here they seem to disappear, and in the Birdsall country are scarcely recognizable, although they may be represented by a thin calcareous band about a foot thick, seen in the top of the larger quarry at this place, and also by some impure limestones that occur near Toft House at the foot of Picksharp Wood.

LOWER LIMESTONE.

ZONE OF AMMONITES PERARMATUS. (Upper part.)

This division was formerly included with the Upper Limestone in one general mass under the term Coralline Oolite, but in tracing the outcrop across the country we have been able to show that these two are stratigraphically distinct, and Mr. Hudleston has also pointed out that on palæontological grounds they are very different and contain quite a distinct fauna.

Synonyms :—"Coral Rag and Pisolite or Oolite" (part of), W. Smith, Map of Yorkshire, 1821; "The Oolite" and "the Limestone" below (part of),† Young and Bird, Geol. of the Yorkshire Coast, 1822; "Coralline Oolite" (part of), Phillips, Geol. of the Yorkshire Coast, 1829 and 1875; "The Lower Limestones," and "Hambleton Oolites," Blake and Hudleston, Quart. Journ. Geol. Soc., vol. xxxiii., p. 323; also Hudleston, "The Yorkshire Oolites," Proc. Geol. Assoc., vol. v., p. 407, 1878; "The Lower Limestones," Expl. of 95 S.W., p. 18 (Geol. Survey), 1880; "Zone of *Ammonites perarmatus*" (upper part), Hudleston, Geol. Mag., p. 247, 1880; "Oxford Oolite," Blake, Quart. Journ. Geol. Soc., vol. xxxvii., p. 567, 1881.

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* Quart. Journ. Geol. Soc., vol. xxxiii., p. 364.

† The position of this Limestone is excessively confused by these authors, several different horizons being included with it; they seem to have been led entirely by lithological resemblance.

Palæontologically the whole of the strata between the Oxford and Kimeridge Clays are, as we have noticed, separable into two groups, the principal division between which occurs near the top of the Lower Limestone. In the lower of these series the fossils have more affinity with the Oxfordian beds, while the upper series, allowing for the difference of conditions under which they were formed, may be said to foreshadow the fauna of the Kimeridge Clay. At the top of the Lower Limestone, throughout part of the area to the west of Pickering, there is a thin shell-bed, the fauna of which are more nearly allied to that of the higher beds, and therefore might be classed with them, although of course the principal physical break, and the only one that can be mapped is above this bed.

The following is the list given by Mr. Hudleston of the common or characteristic fossils of the Lower Limestone exclusive of the top shell-bed:—

Ammonites Williamsoni, *Phil.*
—— goliathus, *d'Orb.*
—— cordatus, *Sow.*
—— vertebralis, *Sow.*
Alaria bispinosa, *Phil.*
Pleurotomaria Münsteri, *Goldf.*
v.c. Cylindrites elongatus, *Phil.*
Goniomya literata, *Sow.*
Myacites, &c., several forms.
c. Astarte extensa, *Phil.*
c. Trigonia clavellata, *Sow.*
—— triquetra, *Seebach.*
—— snaintonensis, *Lyc.*
Arca æmula, *Phil.*
v.c. Gervillia aviculoides, *Sow.*
c. Avicula expansa, *Phil.*
c. —— ovalis, *Sow.*
Lima læviuscula, *Sow.* var.
—— gibbosa, *Sow.*
v.c. Pecten sub-fibrosus, *d'Orb.*
v.c. Exogyra nana, *Sow.*, includes E. spiralis, *Goldf.*
Ostrea flabelloides, *Lam.* var.
Terebratula fileyensis, *Walker.*
Waldheimia Hudlestoni, *Walker.*
v.c. Rhynchonella Thurmanni, *Voltz.*
Cidaris Smithii, *Wr.* (small).
Acrosalenia decorata, *Haime.*
Collyrites bicordata, *Leske.* (small).
Echinobrissus cf. clunicularis, *Llhwyd.*
v.c. Echinobrissus scutatus, *Lam.*
Pygurus pentagonalis, *Phil.* (small).
c. Millericrinus echinatus, *Goldf.*
Spongia floriceps, *Phil.*

The Lower Limestones are far less fossiliferous than the Upper Limestones, and may be at once distinguished from them by the paucity of their organic contents, or by the presence of the commoner fossils in the above list.

They form an elliptical mass which is thickest in the centre, and apparently thins out around the edges. In the centre, where these beds are consequently best developed, they are composed of whitish oolite usually fine in texture with softer and more earthy partings, the lower part of the rock being more flaggy and siliceous, and passing gradually into the Passage Beds which are sufficiently distinct from either the Limestone or the Lower Calcareous Grit to be treated as a separate division. Towards the east or rather south-east these beds thin out, or their place is occupied by the impure gritty limestones of the Passage Beds; along part of the northern outcrop they also thin out; while toward the west they become converted into siliceous beds still retaining the oolitic structure, which further west are split up into two or three distinct bands and finally die out altogether. It therefore appears that the present outcrop occupies nearly the

original limits of the limestone, and that the thinning out of the beds in all directions, as far as we know, is not due to denudation but to non-deposition.

The general outcrop of the Coralline Oolite flanks the range of hills formed by the Lower Calcareous Grit encircling the Vale of Pickering, rising on their inner margin, and dipping regularly below the Upper Calcareous Grit and Kimeridge Clay of that valley, except at a few places where the continuity is broken by large faults. On the northern side of the valley the beds are clearly separable into three divisions, and their outcrop can be traced forming three concentric bands; but on the south from the dying out of the intermediate grit this cannot be done, and the whole has to be treated as one formation.

In the cliff section from Filey westwards the Lower Limestones can scarcely be said to be recognised apart from the Passage Beds, the only indication of them being a little oolitic limestone which is seen peeping out from beneath the Drift on the edge of the cliffs above Newbiggin. The only clear section on the coast is that on the outlier at Scarborough, where there are nearly 30 feet of good oolitic limestone above the Passage Beds.* There is little doubt however that these limestones exist beneath the covering of Drift along the main outcrop to the south, and were penetrated in the well at Osgodby, but the account is not sufficiently explicit to enable us to make out the thickness of this division.

Well of the Scarborough Waterworks, between Osgodby and Cayton.

	Ft.	In.
Earth and clay	5	3
Brown clay	19	6
,, ,, with Boulders	4	0
Sand and Gravel	6	0
Fine grey Sand	2	0
Ragged Limestones (commonly called "Roundheads")	5	6
Limestone with soft yellow gritty partings	31	11
Yellow Grit and Limestone†	2	1
Limestone with soft yellow gritty partings	15	9
Limestone with soft yellow gritty partings.‡ This part of the stone is of a dark blue colour and very strong	45	0
Shale	0	6
Total	137	6

In this section the whole of the rock has been marked as limestone, but Mr. Arundel, who sank the well, informs me that it is similar to that forming the Castle Hill at Scarborough. It is probable that nearly the whole thickness of the Coralline Oolite

* *See* page 318.

† It is possible these may represent the horizon of the Middle Calcareous Grit.

‡ These beds are marked as Calcareous Grit in an account which we have from Mr. Filliter, the engineer for the Scarborough Waterworks.

and Calcareous Grit were pierced in this well, but the information is not definite enough to be certain of the several divisions.

On either side of the valley just north of Seamer Station the Lower Limestones get clear of Drift, and may be easily followed along the northern edge of the limestone outcrop, although their separation from the upper division is at first not very clear. They are exposed in several small quarries, amongst others at Waydale House, Irton Moor, and White Quarry in Forge Valley where there are rather over 30 feet of these beds. Throughout this region the characteristic fossils *Cylindrites elongatus, Gervillia aviculoides, Rhynchonella Thurmanni* together with *Ostrea* and *Pecten,* are abundant; there are also indications of a slight development of Coral Rag towards the base of the limestone similar to that at Hackness where it is much better seen.

On the outlier at Hackness there are several patches of the Lower Limestone cropping out on the hill-tops around the Hall, but separated from one another by the numerous branching dales which unite near that spot. This outcrop is particularly interesting from its containing at the base about 6 feet of Coral Rag which, although there are indications of coral here and there in the Lower Limestone to the south and west, is nowhere so finely developed as on this outlier. This bed, which is called by the workmen "Cold Head," has a peculiar rubbly character, and consists of impure siliceous limestone abounding with corals of the genera *Thamnastræa* and *Isastræa.* In fact it is a regular coral bed, similar to that occurring at Brompton and Ayton, but occupying a lower horizon, and containing a different fauna. It is quarried at several places for mending the roads, and being very hard is fairly well suited for the purpose. Wherever this bed covers the surface for any distance it forms very good land, and the sweetest pastures of the district occur on it.

Messrs. Blake and Hudleston give the following section and list of fossils from this bed.*

Section of Suffield "Sandstone" Quarry.

	Ft.	In.
a. Soil and broken Rag - - - - -	0	6
b. Crystalline gritty coral-doggers in a brownish brash containing abundance of small *Waldheimia,* with *Spongia floriceps* and many other fossils - - - - - - - - -	3	0
c. Massive coralline block with shell-tablets. *Cidaris Smithii* (spines and test), *Trichites,* &c. - - - - - - -	1	9
d. Flaggy shelly bed with a few corals imbedded in a brown gritty limestone - - - - - - - - -	2	0
e. Ferruginous brashy parting, with seams of ferric hydrate - -	1	0
	8	3

"These rest upon flaggy ferruginous limestone largely made up of broken shelly matter.

* Quart. Journ. Geol Soc., vol. xxxiii., p. 331.

"The fossils of the Rag, chiefly occurring in *b*, are numerous and interesting. There are some peculiar forms of *Ostrea*. The list includes *Ostrea*, sp., *O. gregaria*, *O. solitaria*, *Exogyra nana*, *Gryphæa chamæformis?* *Pecten fibrosus*, *P. articulatus* (dwarf), *Hinnites velatus*, *Lima rudis*, *Lima*, sp., *Trichites*, *Cypricardia* (small), *Astarte rhomboidalis* (small), *Waldheimia Hudlestoni*, *Cidaris Smithii*, *Spongia floriceps*, *Serpula tricarinata*. The corals present more variety than might be found in an equal amount of the Upper (true) Coral Rag of the district. We found *Isastræa explanata*, *Thamnastræa concinna*, *Thecosmilia annularis*, and *Rhabdophyllia Phillipsi*, with the inevitable *Modiola inclusa*."

This Coral Bed is best seen at Suffield, Silpho, and Broxa, but there are indications of its extending as far south as Seamer Moor and as far west as Bickley and possibly Thornton Dale.

Above the Coral Bed we have the main mass of the Lower Limestone which at Hackness has a thickness of about 30 feet. It consists of thick beds of oolite with sandy partings, and is easily distinguished from the Limestone above by the paucity of its fossils. It contains however the usual forms common to the lower portion of the Coralline Oolite, such as *Gervillia aviculoides*, *Ostrea flabelloides*, *Exogyra nana*, &c. The following section in the outlier on the south side of the Hall is taken from Messrs. Blake and Hudleston.

Section in Suffield Lime-quarry.

	Ft.	In.
a. Thin-bedded shelly limestones in which the forms are partially obliterated. *Cerithium muricatum* (rare), *Exogyra nana*, *Ostrea gregaria*, *Pecten fibrosus*, *Trigonia*, sp. (rare), *Echinobrissus*, sp. (cf. *clunicularis*), *E. scutatus*; fauna micromorphic - -	4	0
b. Small-grained oolites with few fossils, forming the mass of the limestone - - - - - - - -	10	0
c. Fossiliferous suboolitic limestones with *Ammonites cordatus*, *Avicula inæquivalvis* (? *expansa*), *Gervillia aviculoides*, *Perna quadrata*; fauna megalomorphic. To floor of quarry, below which there may be some 6 or 8 feet before reaching the next series - -	3	6
	17	6

West of the Derwent the outcrop of the Lower Limestone strikes across the hills in a south-west direction in a narrow but conspicuous band which has been frequently quarried, and where the usual fossils may be obtained. Beyond Brompton from the flattening out of the dip these beds creep up the hill towards the north, and spread over a much larger area. Owing to the elevation of the strata between Brompton and Thornton along the southern edge of this area the Limestone crops out to the south as well as to the north, and it is very noticeable how much thicker and more important a rock it is to the south than to the north. On the edge of the hill above Allerston there is over 50 feet of this limestone, while along the northern edge of the outcrop about Jingleby House there cannot be more than 10 feet or so.

At Thornton Dale the Lower Limestone is well developed, and there are good sections in the quarries on both sides of this

picturesque gorge. In the Caulklands quarry on the east side Messrs. Blake and Hudleston give the following description of the beds* :—

Section in the Further Quarry East of Thornton Dale.

	Ft.	In.
1. Fine-grained oolites, measured down to a line of intermittent coral (*Thamnastræa*), partly silicified	14	0
2. Oolitic limestone of similar character	11	0
3. Stronger-bedded oolitic limestone, with tuberous and spherical masses of silicified oolite	3	0
	28	0

"These coral masses are of excessive interest, as being on an horizon not far removed from that of the Lower Coral Rag of Hackness. The silicification of the oolite seems also an important feature in the Lower Limestone here, as we shall see further west. The limestones, as usual, are not fossiliferous; but we noted the following:—*Pleurotomaria Münsteri, Chemnitzia heddingtonensis* (rare), *Cylindrites elongatus, Anomia radiata, Avicula ovalis, Lima fragilis, Pecten fibrosus, Gervillia aviculoides, Trigonia* (clavellate species), *Lucina Beanii, Echinobrissus scutatus.* In an adjoining quarry about 35 feet of oolites are seen, of which 17 feet lie above those last measured. Towards the base there are abundance of *Gervillia;* and towards the top, of *Nerinæa.* The several beds have red clay partings, and contain also *Exogyra nana, Perna quadrata,* and plates of *Astrogonium.*"

We have also from these quarries *Ostrea gregaria, Ostrea solitaria, Isocardia tenera, Ammonites cordatus, Cypricardia* sp., and *Astarte.*

On the west side of the valley this limestone is exposed in the quarry alongside of the upper road, where its junction with the sandstone above is well seen.† The following fossils are mentioned by Messrs. Blake and Hudleston from the shell-bed at the top of the limestone. *Belemnites abbreviatus, Chemnitzia heddingtonensis, Perna quadrata, Avicula pteropernoides, Pecten lens, P. fibrosus, Anomia radiata, Trigonia* (clavellate sp.), *Lucina Beanii* (*aliena ?*).

To the north of Thornton the Lower Limestone has its broadest outcrop, which runs out to the north as far as Levisham and Lockton, and covers a wider extent of country than anywhere else in this range of hills. Throughout the whole of this extended outcrop it is frequently quarried, but there is nothing very noticeable in the bed, more than that it is either a hard limestone or sandy oolite generally poor in fossils.

In the narrow gorge north of Pickering the Lower Limestone has also a very extended outcrop; it is first exposed in the bottom of the valley, where the road to Newton crosses the railroad, and,

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* Quart. Journ. Geol. Soc., vol. xxxiii., p. 341.

† *See* section on page 339.

rising gradually to the north east, forms a narrow band in the steep wooded banks on either side till some distance beyond Kingthorpe, when it spreads out over the surface, and may be traced uninterruptedly to Cropton. It is largely quarried in this region, especially at the latter village, where this bed and the Passage Beds below attain a considerable thickness, and are well worthy of study.

Messrs. Blake and Hudleston in alluding to this section say: "As in the great quarry of these oolites near Thornton Dale, there is a face of nearly 40 feet of small-grained suboolitic limestone in very large blocks. The general resemblance of the rocks to some of the less fossiliferous portions of the oolite of the Upper Limestones (Coralline Oolite) might cause even an experienced palæontologist to doubt the true position of these beds without the aid of stratigraphical evidence, here fortunately of a most unmistakable character. Still the prevalence of *Gervillia*, abundant in one of the lower blocks, rather than of *Chemnitzia*, is a point of difference which may always be relied upon; doubtless a closer inspection would reveal additional points. The other fossils noted were *Pecten subfibrosus*, *Avicula lævis*, *Trichites*, *Lucina Beanii*."*

In this area the shell-bed at the top of the limestone is very well seen, especially in the little dales south-west of Newton, where several quarries have been opened on the line of junction between the limestone and overlying sandstone. This band is very thin but crowded with fossils, and seems to show that the fauna flourishing during the deposition of the limestone were suddenly exterminated by the irruption of sandy matter into the sea of that period. This shelly cap of the rock is also seen in the gorge of the Seven just north of Sinnington, where 5 feet of coarse hackly oolite with pisolitic grains are exposed, from which Messrs. Blake and Hudleston give the following fossils:—*Ammonites cordatus*, *Chemnitzia heddingtonensis* (fine), *Exogyra nana*, *Anomia* sp., *Pecten fibrosus*, *Gervillia aviculoides*, *Lucina Beanii* (v.c.), *Opis Phillipsi*, *Myacites* sp., *Trigonia perlata*.†

This shell-bed has been shown by Mr. Hudleston to belong, on biological grounds, to our next group or zone of *Am. plicatilis*, but we have included it here on account of its forming part of the great physical division of the Lower Limestone, and consequently one of the main features of the district, which it is most advantageous to adopt in a general description of the country.

West of the Seven the Lower Limestone spreads out over a considerable area between Spaunton and Appleton-le-Moor, and is exposed in several good sections in the sides of Hutton Beck and the valley of the Dove. The former of these valleys is one of the best localities for studying the Middle Oolites. The beck is usually dry for a great part of the year, and at one point or another presents sections of nearly every portion of the group.

* Quart. Journ. Geol. Soc., vol. xxxiii., p. 343.

† *Ibid.*, p. 344. Compare also Proc. Geol. Assoc., vol. v., p. 417.

The following section was measured in the quarry on Hutton Common:—

	Ft.	In.
Yellow sandstone (base only seen).		
Earthy limestone with *Gervillia aviculoides*	6	0
Hard grey limestone	2	6
Shaly limestone	2	6
Thick bed of limestone full of *Ostrea gregaria*	2	0
Thick bed of limestone	2	0
Cherty nodules	1	6
Hard grey limestone	1	0
Cherty nodules	0	9
Hard cherty limestone rich in fossils, *Echinobrissus scutatus*, *Gervillia aviculoides*, *Ostrea gregaria*, *Exogyra nana*, *Chemnitzia heddingtonensis*, *Cylindrites elongatus* and *Nerinæa*	11	4

On the further side of Dowthwaite Dale, near Gillamoor, there are some large quarries in this oolite which expose a section of nearly 60 feet, and as this is not the full thickness of the rock, it must here attain a very great, if not its maximum, development. West of this the Limestone becomes very siliceous, and covers a large area of poorish land north of Pockley and Helmsley. A curious feature in this part of the country is the great quantity of white siliceous fragments which strew the sides of the dales, more particularly Riccal Dale, giving them the appearance of Chalk escarpments.

Messrs. Blake and Hudleston in noticing this peculiar silicification of the beds about here say*:—"Sections of the oolitic grains show the concentric structure; and they are coloured brown or black by the presence of carbon, as in ordinary flint, with a trace probably of iron. They are imbedded in a white matrix, which is almost pure silex, while every crack, exposed surface, or fossil is covered with the same substance in the form of beekite. These features are well seen in quarries behind Skiplam wood and Oxclose wood."

Some of the quarries in this region have a peculiar fibrous siliceous rock, which has very much the appearance of fossil wood, and is not unlike specimens from Portland in the south of England. This was seen in Oxclose† quarry east of Hutton Beck and in Newlass quarry near Rievaulx.

Beyond the Rye the Lower Limestone becomes much thinner, or rather splits up into two thin beds separated by a band of sandstone; the lower of these crops out in the sides of the narrow dales between Scawton and Cold Kirkby, while the upper band caps the hill at these places, and covers a large area of surface.

At King Spring at the head of the dale north of Old Byland the relation of these two bands of limestone to the intermediate sandstone is very clear, but a short distance north of this the sandstone crops out over the surface of the moor, so that we cannot be sure whether it thins out in this direction. In attempting to trace

* Quart. Journ. Geol. Soc., vol. xxxiii., p. 345.

† There are two places of this name; the one mentioned by Messrs. Blake and Hudleston is north-west of Pockley.

it eastwards towards Murton, however, it very soon dies out, so that it is probable that the limestone north of this is the amalgamated representative of these two bands. In this area, which is the north-west limit of its outcrop, the Lower Limestone has a considerable development; and between Hawnby and Kepwick, which seems to be the line of greatest thickness, there may be as much as from 50 to 80 feet, although from there being no deep sections, and from the tendency of the rock to slip over the escarpments, it is not easy to estimate it very exactly. This thickness probably includes some sandy subdivisions; there does not appear to be so much pure limestone here as about Dowthwaite Dale to the north of Kirkby Moorside.

In this district the limestone is fairly massive, but a much more barren rock than it is further east, in fact the paucity of fossils is remarkable. At Kepwick there are extensive quarries which have been worked for a number of years, from which Messrs. Blake and Hudleston quote the following fossils:—*Belemnites*, *Ammonites cordatus*, *Nerinæa*, *Avicula ovalis*, *Avicula expansa*, *Avicula lævis*, *Pecten lens*, *Lima elliptica*, *Lucina*, *Rhynchonella Thurmanni*, *Echinobrissus scutatus* (abundant), *Holectypus oblongus*, *Astropecten* (fragments). From Kepwick southwards the limestone may be traced along the edge of the great western escarpment to Boltby Scar, where as we have seen it is only 16 feet thick, while about the same thickness of sandstone is exposed above.

This upper sandstone occupies the crest of the hill, and is probably somewhat thicker than shown in the scar, as it is some little way before the upper band of limestone comes on. It is the same bed as that we have just noticed on the opposite side of the hill at King Spring, north of which it dies out; here apparently the limestone also is becoming thinner as we have been unable to trace it any further to the south. The fact is in this region the base of Limestone and the top of the Lower Calcareous Grit are dovetailed together, producing an alternating series of sandstones and limestones, which to the north develop into one thick bed of limestone, while to the south first the lower band of limestone dies out and then the upper, so that in the south-east of this range of hills there is only one thick mass of arenaceous strata to represent the whole of these limestones.

On Boltby Moor the upper band of limestone, which is the one covering nearly the whole surface of the hill between here and the Rye, is very fissile, and splits up into flags, which has given rise to such names as "Slate Quarries" and "Flag Quarry" in the map of this district.

At the base of the Lower Calcareous Grit below Shaws Moor there is a band of oolitic limestone which has a thickness of about 30 feet, but it is evidently of very limited extent as it cannot be followed very far in either direction; and in Roulston Scar which is only about a mile distant there is not a trace of it. It is very possible that this is the same bed as that occurring in the valley below Cold Kirkby and Scawton; and if so the same

as that in Boltby Scar, although it occupies a slightly different position.

At Cold Cam the Limestone is becoming thinner, and to the east and south of this it rapidly dies out, so that it cannot be traced beyond Sproxton Moor and Wass respectively, although there are indications of the bed as far as Ampleforth. Here there are about 6 feet of impure limestone with oolitic grains on this horizon, which serve to mark the division between the Lower and Middle Calcareous Grit. The fields above the village are also said to be more calcareous, and the land better, just along the outcrop of this bed.

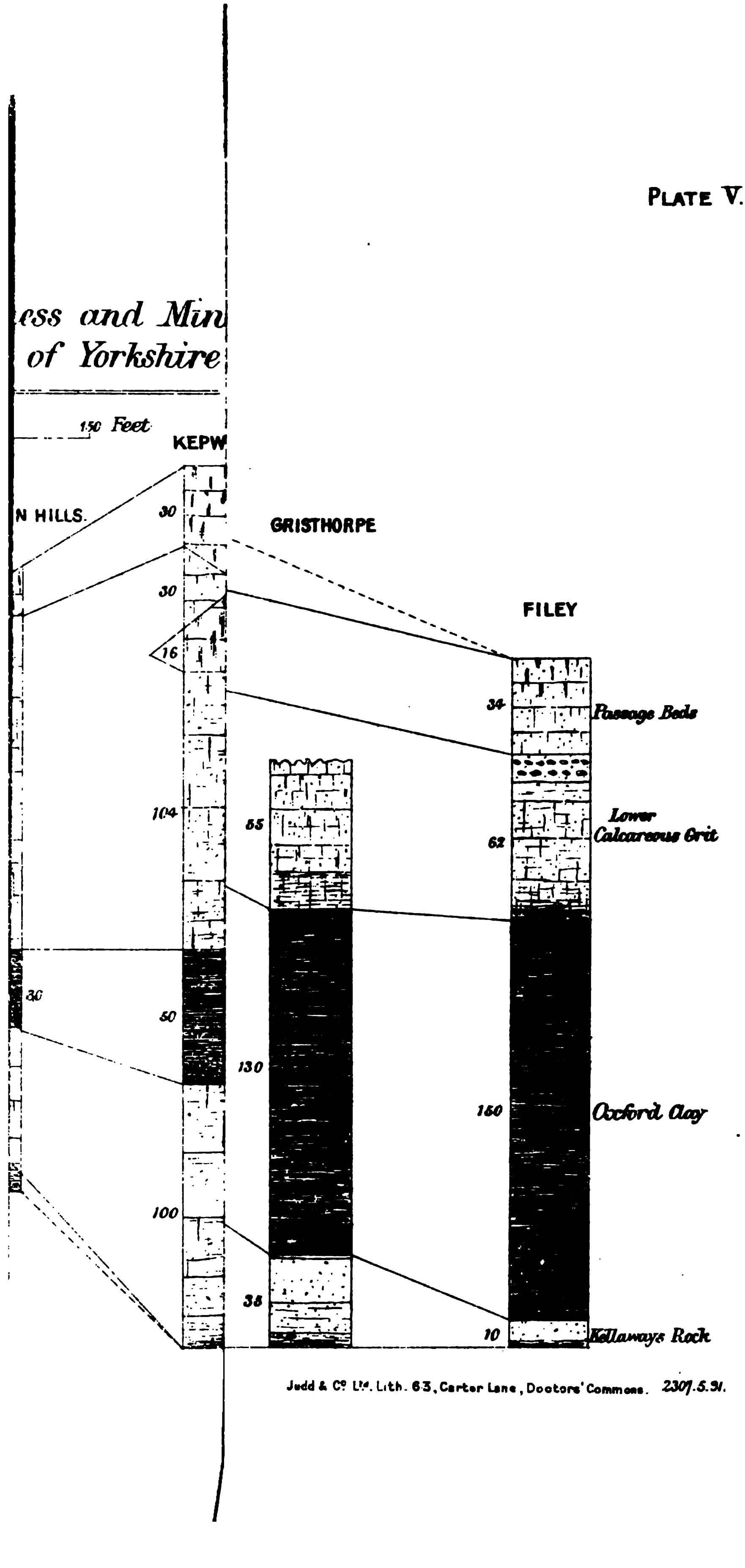
Just east of this, from the gradual decline of the beds in that direction, this narrow band is brought down against the large fault which bounds these hills and brings up the Kimeridge Clay, so that it is lost sight of; the sandstone worked in the quarries behind Ampleforth College and eastwards to Oswaldkirk being apparently above this horizon.

On the opposite side of the valley along the Howardian range the Lower Limestone has not been made out for certain, although there is very little doubt that it is to some extent represented by the narrow band just above the brow of Slingsby Bank, and by the limestones that are quarried at Barton, Appleton, and nearly as far as Malton. If this is the case it would appear that we have here in the Howardian Hills a second instance of the dovetailing together of the sandstone and limestone; the lower part of the limestone thinning out west, while the upper part of the sandstone thins out east.

At Appleton-le-Street which lies nearly on an axis of upheaval, the lower part of the limestone is exposed in numerous quarries. It consists of alternations of impure oolitic beds, and soft yellowish brash crowded with *Echinobrissus scutatus*, although containing but few other fossils. Only a few feet of limestone is to be seen here; and there is not much direct evidence, except the paucity of organic remains, that this is the Lower Limestone of the Tabular range.

At North Grimston, also, the lower part of the limestone consists of soft marly oolites with *Echinobrissus scutatus*, which probably belongs to this series; but as there is no very marked separation between this and the higher beds, we must defer a further account of this rock till we come to treat of the Upper Limestone, which is the important bed in this neighbourhood.

PLATE V.



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CHAPTER XIV

THE MIDDLE OOLITES—(*continued*).

CORALLIAN ROCKS.—PART II.

THE ZONE OF AMMONITES PLICATILIS.

THIS is the second of the great groups into which the Corallian Rocks are capable of being divided. It includes the Middle Calcareous Grit, the Upper Limestone, the Coral Rag, and the Upper Calcareous Grit. The fauna of these rocks is very distinct from the beds below, and has been shown to be characteristic of the true Corallian of foreign authors. Portions of this division have been referred to the zones of *Cidaris florigemma*, *Glypticus hieroglyphicus*, *Ammonites plicatilis*, and other fossils which are more abundant in particular localities; but the latter of these seems to be the best to apply to the Yorkshire Rocks, as ammonites allied to this species are more generally prevalent throughout this horizon, and here attain their finest development, although they occur also to a certain extent in the beds below.

*Synonyms and Foreign Equivalents**:—"Limestone of the Vale of Pickering" (part), Smith, Table to the Map, 1812; "Coral Rag and Pisolite" (part), Smith, Strata identified by organized fossils, 1816; "Oolitic strata associated with the Coral Rag" (part), Conybeare and Phillips, Outlines of Geology, p. 166, 1822; "The Oolite" (part), Young and Bird, Geol. Survey of the Yorksh. Coast, p. 61, 1822; "Coralline Oolite" (part), and "Upper Calcareous Grit," Phillips, Geol. of the Yorkshire Coast, p. 33, 1829; "Calcaire corallique *moins* le Sable ocreux," Brongniart, Tableau des Terrains, pp. viii., 410, 1829; "Oolitic Limestone" (part), Smith, Geol. Map of Hackness, 1832; "Terrain à chailles† (part), calcaire et oolite corallienne," Thurmann, Essai sur les soulevemens, 1832; "Calcaire coralliens" (part), Thirria, Statistique de la Haute Saône, p. 150, 1833; "Wahrer Korallen-Kalk, Dolomit des Coral rags, und Oberer Coral rag," Röm. Verst. Ool., pp. 9, 10, 1836; "Weisser Jura δ: Regelmässig geschichtete Kalkbänke," Quenstedt, Flözgebirge, p. 536, 1843; "Étage Corallien," d'Orbigny, Terrains jurassiques, p. 609, 1844; "Calcaire corallien et Oolite corallienne," Marcou, Jura salinois, p. 100, 1848; "Zone des *Cidaris florigemma*," Oppel, Juraformation, p. 646, 1856; "Zone of *Ammonites plicatilis*," Hudleston, Geol. Mag., 1880, p. 247.

In the previous chapter we gave a list of the fossils that have been found in the lower part of the Corallian series, or zone of *Am. perarmatus*; we will now consider those occurring in the upper part of these rocks, that is the Upper Limestone and Coral Rag, or zone of *Am. plicatilis*, as it may be more generally called. By comparing this list with that given on pages 302, 303, we note that these higher beds differ from those below, especially in the abundance of gasteropoda, for which the little creeks and pools surrounding the coral reefs seem to have been particularly

* It is probable that many of the Foreign Equivalents given above include in some cases more, in other cases less, than the Yorkshire beds with which we corellate them; but without carrying on researches among the Continental rocks it is not possible always to give exact equivalents.

† This is merely a petrological term and does not signify a definite horizon as has been supposed. There are three "Terrains à chaille," one in the Lower Oxfordian, one in the Upper Oxfordian, and one in the Corallian.

favourable; whilst in the general mass of the limestone *Chemnitzia heddingtonensis* is so abundant as to give its name to a large portion of these beds, which are almost made up of this particular shell.

The lamellibranchiata are also more numerous than in the lower beds, and there are certain species which may be taken as characteristic of these limestones; these are *Astarte ovata, Lucina aliena, Lima læviuscula, Lima rigida,* the several species of *Corbicella, Arca, Cucullæa,* &c.; and also *Trigonia perlata, T. Meriani,* and some other forms.

With regard to the cephalopoda the same species of Belemnites range throughout the whole of the Corallian series, although their forms are somewhat modified in the upper beds. The Ammonites, however, show some distinction; for, although those of the *Am. cordatus* group occur in both, the general form in these upper beds appears to be one allied to *Am. plicatilis,* while *Am. perarmatus* is very rare.

The echinodermata again are very characteristic, many of the species enumerated in the table being confined to these beds, while the increase in size of some of those that are common to the two horizons is remarkable. Throughout the western portion of the district the spines of *Cidaris florigemma* are so plentiful and characteristic as to suggest the adoption of this species as the type of the zone; which no doubt would have been preferable to that of *Am. plicatilis* if the species had occurred over the whole area.

Lastly, the Brachiopoda, although very rare in the upper beds, are nevertheless represented by some species that are confined to this horizon.

Fossils of the Upper Limestone and Coral Rag, or Zone of Ammonites plicatilis.

PLANTÆ.

Araucarites Hudlestoni, *Carr.*
Carpolithes conicus, *L. & H.*
Carpolithes plenus, *Phil.*

ACTINOZOA.

Cladophyllia Conybearii, *M. Edw.*
Comoseris irradians, *M. Edw.*
Goniocora socialis, *Röm.*
Isastræa explanata, *Goldf.*
—— inæqualis, *Phil.*
Latimæandraræa decorata, *Bean.*
Montlivaltia dispar, *Phil.*
Rhabdophyllia Phillipsi, *M. Edw.*
Stylina tubulifera, *Phil.*
Thamnastræa arachnoides, *Park.*
—— concinna, *Goldf.*
Thecosmilia annularis, *Flem.*

ECHINODERMATA.

Cidaris florigemma, *Phil.*
—— Smithii, *Wright.*
Collyrites bicordata, *Leske.* (large).
Echinobrissus dimidiatus, *Phil.*
—— scutatus, *Lam.*
Glypticus hieroglyphicus, *Goldf.*
Hemicidaris intermedia, *Flem.*
Holectypus depressus, *Leske.*
Pseudodiadema hemisphæricum *Ag.*
Pseudodiadema versipora, *Phil.*
Pygaster umbrella, *Ag.*
Pygurus Hausmanni, *K. & D.*
—— pentagonalis, *Phil.*
—— Phillipsii, *Wright.*
Stomechinus gyratus, *Ag.*
Apiocrinus polycyphus, *Desor.*
Millericrinus, sp.
Pentacrinus, sp.

ANNELIDA.

Serpula deplexa, *Phil.*
Serpula squamosa, *Phil.*

BRACHIOPODA.

Terebratula bisuffarcinata, *Ziet.*
—— insignis, *Schüb.* var. maltonensis, *Oppel.*
—— repeliniana, *d'Orb.*
Thecidium, sp.
Waldheimia boloniensis, *S. & R.*
—— Gesneri, *Et.*
—— margarita, *Oppel.*

LAMELLIBRANCHIATA.

Anomia radiata, *Phil.*
Avicula expansa. *Phil.*
—— ovalis, *Phil.*
—— pteropernoides, *Bl. & H.*
—— Struckmanni, *De Lor.*
Exogyra nana, *Sow.*
Gervillia angustata, *Röm.*
—— aviculoides, *Sow.*
Gryphæa dilatata, *Sow.*
—— —— var. bullata, *Sow.*
Hinnites tumidus, *Ziet.*
Lima densipunctata, *Röm.*
—— elliptica, *Whit.*
—— fragilis, *Röm.*
—— grandis, *Röm.*
—— læviuscula, *Sow.*
—— pectiniformis, *Schlot.*
—— rigida, *Sow.*
—— rudis, *Sow.*
—— subantiquata, *Röm.*
Ostrea duriuscula, *Phil.*
—— gregaria, *Sow.*
—— moreana, *Buvig.*
—— solitaria, *Sow.*
Pecten articulatus, *Schlot.* (P. vimineus, *Sow.*)
—— comatus, *Münst.*
—— demissus, *Phil.*
—— fibrosus, *Sow.*
—— inæquicostatus, *Phil.*
—— intertextus, *Röm.*
—— lens, *Sow.*
—— qualicosta, *Et.*
—— vagans, *Sow.*
Perna mytiloides, *Lam.*
—— rugosa, *Goldf.* (P. quadrata *Phil.*)
—— subplana, *Etallon.*
—— sp. n. ("inoceramoides," *Hud.*)
Plicatula fistulosa, *L. & M.*
—— sp. n. ("subinflata," *Hud.*)
Trichites Plottii, *Llhwyd.*
Anatina siliqua, *Ag.*
Arca æmula, *Phil.*
—— lanthanon, *Bl. & H.*
—— quadrisulcata, *Sow.*
Astarte aytonensis, *Bean* in *Lyc.*
—— depressa, *Münst.*
—— duboisiana, *d'Orb.*
—— ovata, *Smith.*
—— rhomboidalis, *Phil.*
Cardium cyreniforme, *Buvig.*
—— isocardioides, *Bl. & H.*
Corbicella Buvignieri, *Desh.*
—— decussata, *Buvig.*
—— lævis, *Sow.*
Corbicella uniformis, *Bean, MS.*
Cucullæa corallina, *Damon.*
—— elongata, *Phil.*
—— pectinata, *Phil.*
Cypricardia glabra, *Bl. & H.*
—— sp. n. ("corallina," *Hud.*)
Cyprina corallina, *d'Orb.*
Gastrochæna moreana, *Buvig.*
Goniomya literata, *Sow.*
—— v-scripta, *Sow.*
Gresslya peregrina, *Phil.*
Homomya crassiuscula, *L. & M.*
—— tremula, *Buvig.*
—— sp. n. ("grimstonensis," *Hud.*)
Limopsis corallensis, *Buvig.*
Lithodomus inclusus, *Phil.*
Lucina aliena, *Phil.*
—— ampliata, *Phil.*
—— aspera, *Buvig.*
—— Beanii, *Lyc.*
—— moreana, *Buvig.*
—— oculus, *Bl. & H.*
—— substriata, *Röm.*
Modiola cancellata, *Röm.*
—— Lycetti, *Whit.*
—— subæquiplicata, *Goldf.*
—— ungulata, *Y. & B.*
—— sp. n. ("gibbosa," *Hud.*)
Myacites decurtatus, *Phil.*
—— jurassi, *Brong.*
—— recurvus, *Phil.*
Myoconcha Sæmanni, *Dollf.*
—— texta, *Buvig.*
Mytilus? jurensis, *Merian.*
—— pectinatus, *Sow.*
Opis corallina, *Damon.*
—— excavata, *Röm.*
—— Phillipsi, *Morris.*
—— virdunensis, *Buvig.*
Panopæa gigantea, *Buvig*
Pholadomya æqualis, *Sow.*
—— decemcostata, *Röm.*
—— paucicosta, *Röm.*
Protocardium isocardioides, *Bl. & H.*
Quenstedtia lævigata, *Phil.* (three var.)
Sowerbya triangularis, *Phil.*
Tancredia curtansata, *Phil.*
—— planata, *L. & M.*
Trigonia corallina, *d'Orb.*
—— geographica, *Ag.*
—— Hudlestoni, *Lyc.*
—— Meriani, *Ag.*
—— perlata, *Ag.*
Unicardium depressum, *Phil.*
—— plenum, *Bl. & H.*
—— sp.

GASTEROPODA.

Actæon retusus, *Phil.*
Alaria tridactyla ?, *Buvig.*
Amberleya Buvignieri, *d'Orb.*
—— princeps, *Röm.*
—— Stricklandi, *Hud.*
Aporrhais, sp.
Bulla Beaugrandi, *De Lor.*
Cerithium bicinctum, *Hud.*
—— gradatum, *Hud.*
—— grandineum, *Buvig.*
—— humbertinum, *Buvig.*
—— inornatum, *Buvig.*
—— limæforme, *Röm.*
—— michaelense, *Buvig.*
—— muricatum, *Sow.*
—— russiense, *d'Orb.*
—— trinodule, *Buvig.*
Chemnitzia clytia ?, *d'Orb.*
—— corallina ?, *d'Orb.*
—— heddingtonensis, *Sow.*
—— langtonensis, *Bl. & H.*
—— pollux, *d'Orb.*
Cylindrites, sp.
Littorina muricata, *Sow.* (three var.)
Natica arguta, *Phil.*
—— buccinoidea, *Hud.* (non *Y. & B.*)
—— clymenia, *d'Orb.*
—— clytia, *d'Orb.*
Nerinæa fusiformis, *d'Orb.*
—— Goodhallii, *Sow.*
Nerinæa moreana, *d'Orb.*
—— Römeri, *Phillippi.*
—— pseudo-visurgis, *Hud.*
—— sp.
Neritopsis decussata, *Münst.*
—— Guerrei, *Heb. & Desl.*
—— moreana, *d'Orb.*
Patella rugosa, *Sow.*
Phasianella striata, *Sow.*
—— —— var. bartonensis, *Hud.*
Pleurotomaria Agassizii, *Münst.*
—— reticulata, *Sow.*
Pseudomelania Buvignieri ?, *d'Orb.*
—— calypsoides, *Thurm.*
—— gracilis, *Hud.*
—— sp.
Pterocera sp.
Purpuroidea nodulata, *Y. & B.*
—— tuberosa, *Sow.*
—— sp.
Trochotoma tornatilis, *Phil.*
Trochus acuticarina, *Buvig.*
—— aytonensis, *Bl. & H.*
—— granularis, *Hud.*
—— sp.
Turbo corallensis, *Buvig.*
—— erinus, *d'Orb.*
—— funiculatus, *Phil.*
—— lævis, *Buvig.*
—— Pellati, *De Lor.*

CEPHALOPODA.

Ammonites achilles, *d'Orb.*
—— alternans, *V. Buch.*
—— biplex, *Sow.*
—— cawtonensis, *Bl. & H.*
—— cordatus, *Sow.*
—— —— var. excavatus, *Sow.*
—— perarmatus, *Sow.* (rare).
—— plicatilis, *Sow.*
—— trifidus, *Sow.* (Am. triplicatus, *Auct.*).
Ammonites varicostatus, *Buckl.*
—— vertebralis, *Sow.*
Belemnites abbreviatus, *Mill.* var.
—— hastatus, *Montf.*
—— Owenii, *Pratt.* (rare).
Nautilus aganiticus, *Schlot.*
—— hexagonus, *Sow.*

PISCES.

Cestracion, sp.
Hybodus obtusus, *Ag.*
Mesodon (Pycnodus) umbonatus, *Ag.*
Sphærodus, sp.

REPTILIA.

Ichthyosaurus, sp.
Megalosaurus Bucklandi, *Meyer.*
Pliosaurus grossouvrei, *Sauvage* (P. teretidens, *Owen*).

MIDDLE CALCAREOUS GRIT.

As we have previously mentioned, the Coral Rag and the whole of Oolitic Limestones of the Middle Oolite were originally considered one deposit; but when these beds came to be mapped out in detail by the Geological Survey, in tracing their outcrop across the range of hills on the north side of the Vale of Pickering, it was found that a great development of sandy beds and impure limestones occurred somewhere about the middle of the series, and that as these were followed to the west they became of considerable thickness and importance, satisfactorily dividing the more calcareous beds into an Upper and Lower Limestone. About the same time Mr. Hudleston, who was paying especial attention to the palæontology of this group, noticed that the two limestones contained a distinct fauna, which also separated them into two horizons; and that although the deposits were divisible into several separate areas, still these distinctions held good through all of them.

On referring to the section at Filey given on page 315, it is seen that above the Passage Beds there is a massive bed of sandstone having a thickness of about 10 feet which forms the greater part of the Brig itself; above this there are about 6 feet of alternations of shelly beds and sandstone which become fissile towards the top and are succeeded by the broken irregular oolite of the Upper Limestone. The thick bed of grit is not very fossiliferous and contains only *Avicula ovalis, Gervillia aviculoides, Ostrea bullata, Pecten subfibrosus, Perna quadrata*; but the beds above are much more calcareous, the following list being quoted from them:—

Ammonites cordatus, *Sow.*
—— goliathus, *d'Orb.*
—— plicatilis, *Sow.*
—— perarmatus, *Sow.*, var.
Chemnitzia heddingtonensis, *Sow.*
Nerinæa, sp.
Littorina muricata, *Sow.*, var.
Pleurotomaria Münsteri, *Röm.*
Exogyra nana, *Sow.*
Pecten fibrosus, *Sow.*
—— articulatus, *Schlot.* (P. vimineus, *Sow.*)
Lima, sp.
Lima elliptica, *Whiteaves.*
Gervillia aviculoides, *Sow.* (very large).
Trigonia (clavellate sp).
Lucina Beanii, *Lyc.*
—— sp. (cf. lirata, *Phil.*)
Astarte, sp.
Sowerbya triangularis, *Phil.*
Pholadomya decemcostata, *Röm.*
Myacites jurassi, *Brongn.*
Gresslya peregrina, *Phil.*
Goniomya literata, *Sow.*

After leaving the Filey promontory these beds pass beneath the Drift, so that it is not possible to associate them stratigraphically with the sections inland. In the well-section at Osgodby some gritty beds are mentioned in the middle of the limestone which may be referred to this horizon, but as all these sandstones appear to be more calcareous when met with at any depth from the surface, it is probable that the lithological distinction between them would not be very marked.*

* This Grit is also not distinguishable in the boring at Irton, nearly all the rock brought up at this horizon being apparently limestone.

North of Seamer Station, where the limestones lose their covering of Boulder Clay, a narrow sandy band may be traced across the country to Forge Valley, where a section of these beds is exposed in the steep bank above White Quarry, and in the little gorge formed by Seavegate Gill. Here, above the oolitic beds of the Lower limestone, are several alternations of sandy and calcareous strata more or less oolitic constituting an "Intermediate Series" to which Mr. Hudleston assigns a thickness of 34 feet. This estimate, however, probably includes a portion of the limestone, and therefore more than is the representative of the Middle Calcareous Grit of other places, but the section is not clear enough to obtain an accurate measurement.

West of Forge Valley these sandstones gradually increase in thickness, and occupy a larger space between the two limestones. Along this portion of the outcrop there are frequent indications of the bed, but no good sections occur till we reach the neighbourhood of Brompton, where it is quarried at one or two places for roadstone. Messrs. Blake and Hudlestone give the following account of the upper beds in a quarry, about a mile north of the village :—

Section in Quarry North of Brompton. **B. & H.***

	Ft.	In.
1. Fossiliferous oolites, showing false-bedding. *Chemnitzia heddingtonensis*, *Trigonia* (clavellate and costate), *Astarte duboisiana* (common)	4	6
2. Pale buff grits and oolites mixed. *Phasianella striata*, *Pleurotomaria* sp. *Exogyra nana*, *Avicula ovalis*, *Gervillia aviculoides*, *Sowerbya triangularis*, *Lucina*, sp.; also wood, and curious, vertical, root-like markings	6	6
3. Coarse-grained gritty oolite, with large fossils. *Belemnites abbreviatus*, *Ammonites perarmatus*. *Chemnitzia heddingtonensis* (very large)	4	0
	15	0

A short distance to the west of Brompton the Middle Calcareous Grit has been removed by denudation from the summit of the arch into which the strata are thrown; which has severed the outcrop from that occurring further to the west in the neighbourhood of Thornton Dale and Pickering.

On the Hackness outlier there is a small patch of this sandstone which is rather obscure at its southern end, but spreads out around the hamlet of Silpho, where it contains *Modiola bipartita*, *Pecten articulatus*, and *Terebratula intermedia?*, and forms a red clayey soil with scattered sandstone fragments.

* Sections marked thus **B. & H.** are taken from the excellent and exhaustive work of Messrs. Blake and Hudleston on the Corallian Rocks of England in the Quart. Journ. Geol. Soc., vol. xxxiii. The researches of these authors enter so much more minutely into the palæontological character of the rocks than anything we have attempted in what was a purely stratigraphical survey, that we have availed ourselves freely of these detailed sections; which, to avoid frequent reference, are indicated as above.

Returning again to the main outcrop, we find a large spread of the rock on Dalby Moor, where it occupies nearly the whole of the higher ground, and runs out in a series of long tongues capping the ridges between the numerous valleys that intersect those hills. It here forms very dead cold land covered with heather, the change in vegetation from this land to the calcareous beds below being very sharp and well defined. On these moors there are a number of holes or pits scattered about which at first sight seem to be due to artificial means, but after the examination of a great number of them we came to the conclusion that they owe their origin to the sinking of the strata, caused by the dissolving away of the calcareous beds below.

At Thornton Dale and beyond, the Middle Calcareous Grit becomes much more important, and has been quarried at several places for the beds of freestone it contains.

Section in a Quarry on the West side of Thornton Dale. B. & H.

		Ft.	In.
Middle Calcareous Grit.	Soil and shattered stone - - -	5	0
	Flaggy calcareous sandstone - - -	4	0
	Hard blue rock, slightly oolitic, with *Ammonites plicatilis* - - - - - -	1	6
	Flaggy calcareous sandstone, with some oolite	5	0
	Hard blue rock - - - -	1	2
	Flaggy sandstone, with *Avicula expansa* -	0	6
Top of Lower Limestones.	Principal shell-bed, an impure sub-oolitic limestone - - - - - -	1	3
	Flaggy parting - - - -	0	3
	Lower shell-bed (base of quarry) - -	1	6
		20	2

The best known quarries, however, are those at Pickering, where the following beds belonging to this series are seen just below the Castle:—

Section in Pickering Quarries, East side (lower part).

	Ft.	In.
Solid beds of limestone with *Chemnitzia heddingtonensis* -	5	6
Rubbly oolite, with coarse pisolitic bed - - -	4	0
Thick irregular bed of limestone - - - -	2	6
Oolite with irregular blue-centred limestone, containing *Trigonia perlata* - - - - - - -	4	0
Thin bed full of *Trigonia perlata* - - - -	0	6
Smooth limestone - - - - - - -	1	0
Impure limestone with *Trigonia* bands - - -	5	4
Soft yellow freestones with calcareous bands, containing *Exogyra nana, Gervillia aviculoides, Pecten fibrosus, Cardium, Trigonia costata, T. clavellata, Chemnitzia heddingtonensis, Ammonites biplex.* (Base not seen) - -	11	0

The upper part of this section should probably be classed with the Upper Limestone, and a portion of the beds below might also be considered as representing a passage into them. The beds are, however, so very variable that no two sections are exactly alike; they really consist of an irregular series of sandstones and calcareous beds, in which sandstones largely predominate, especially

towards the lower part; in the upper part several calcareous bands or irregular lenticular masses set in, which foreshadow the conditions of the limestone above, and gradually pass into that formation. These beds on account of the prevalence of *Trigonia perlata* in some of the bands have been called the Trigonia beds; they are very rich in fossils, the following species being enumerated by Messrs. Blake and Hudleston:—*

Fossils of the Trigonia-beds, Pickering.

Belemnites subhastatus, *Mont.*
Ammonites cordatus, *Sow.* (excavatus, Sow.)
—— vertebralis, *Sow.*
—— plicatilis, *Sow.*
Chemnitzia heddingtonensis, *Sow.*
Cerithium muricatum, *Sow.*
Littorina muricata, *Sow.*
Nerinæa visurgis, *Röm.*
—— species (imbricated).
Exogyra nana, *Sow.*
Ostrea solitaria, *Sow.*, var.
Anomia radiata, *Phil.*
Plicatula, sp.
Pecten fibrosus, *Sow.*
—— qualicosta ?, *Et.*
Hinnites (small form).
Lima elliptica, *Whiteaves.*
Avicula ovalis, *Phil.* (peculiar form).
Gervillia aviculoides, *Sow.*
Cucullæa corallina, *Damon.*
Limopsis corallensis, *Buv.*
Trigonia perlata, *Ag.* (many vars.).
—— Meriani, *Ag.*
Cardium cyreniforme, *Buvig.*
Lucina Beanii, *Lyc.*
—— aliena, *Phil.*
—— oculus, *Bl. & H.*
Corbicella, sp.
Cyprina corallina, *d'Orb.*
Cypricardia glabra, *Bl. & H.*
Opis Phillipsi, *Morris.*
Sowerbya triangularis, *Phil.*
Rhynchonella lacunosa, *Schlot.*
Echinobrissus scutatus, *Lam.*
Cidaris Smithii, *Wright.* (spine).
Rhadophyllia Phillipsi, *M.-Edw.* (fragment).

From Pickering the Middle Calcareous Grit, which forms a band about 40 feet in thickness on either side of the gorge, may be followed up the valley to the north for nearly two miles till it spreads out to the north of Blansby Park in a broad tract of dead, sandy land, making a strong contrast to the limestones on either side. To the south of Cropton the outcrop is seen in a few places in the sides of the Seven Valley, and extends in a somewhat obscure course by the north of Appleton to Hutton Beck.

In this beck a very fine section of the rock is again exposed, extending for nearly a mile along the bed and sides of the stream. Some very fine slabs with *Trigonia* are to be seen here, but the greater portion of the rock is a sandstone poor in fossils. The following details were measured along the stream course:—

Section of the Middle Calcareous Grit in Hutton Beck.

	Ft.	In.
Alternations of white and impure oolitic limestones with *Chemnitzia heddingtonensis* in the upper part.		
Soft marly limestone, decomposing into sandstone with minute holes (pinhole structure) - - - - -	2	0
Limestone and impure oolite with long peculiar markings (? fucoids) - - - - - - - -	1	6
Soft sandstone (crops out at the footbridge) - - -	5	0
Hard bed with *Trigonia perlata* passing down into well-bedded sandstones. (Base not seen) - - - about	10	0

* See Quart. Journ. Geol. Soc., vol. xxxiii., p. 336, where a detailed account of these beds is given.

There is probably a considerable thickness of sandstone below this, as the Lower Limestone does not crop out for another half mile, although the beds appear to be steadily rising.

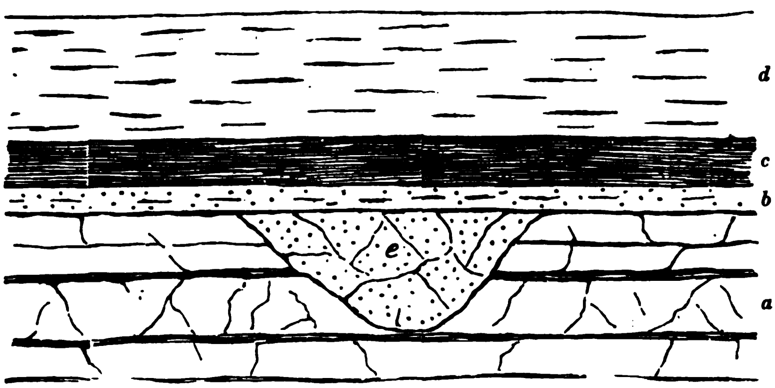
To the north of Kirkby Moorside this rock forms a somewhat large spread by Cockpit Hall and Woolsh House; it is well seen in Kirkdale, opposite the Church; but west of this the outcrop becomes more obscure, although it may be still recognized in Riccal Dale, and to the north of Helmsley. Here it appears to be becoming thinner, although it rapidly thickens again to the south; for just south of the town, in the banks of the Rye below Duncombe Park, there are nearly 80 feet of this rock, which has been quarried below the House, and in Quarry Bank Wood, near Rievaulx.

South of the Rye the Middle Calcareous Grit forms a great spread of barren land on Wass Moor and on Sproxton Moor extending to the hill-edge above Ampleforth.

In a quarry on Wass Moor, of which a woodcut is given below, there is a curious section showing that the Lower Limestone was exposed to denudation before the deposition of the Calcareous Grit above.

FIG. 17.

Limestone Quarry on Wass Moor.



a. Oolitic Limestone. *b.* Reddish Sandstone. *c.* Dark carbonaceous matter, with whitish streaks at bottom. *d.* Red Clay. *e.* Sandstone, filling an old erosion in the Limestone, much fractured.

In the Howardian Hills, to the south of Gilling and Hovingham, the outcrop of this bed has been already described with that of the Lower Calcareous Grit, there being no limestone to separate one from the other; but what takes place at the eastern end of this range is not very clear. As we have seen, the Lower Limestone is well developed about Appleton, but there is no conspicuous division between it and the Upper Limestone of Malton. It is possible, although this did not occur to us at the time the survey was made, that the thin band of limestone noticed near the crest of the escarpment south of Hovingham and Slingsby

is really the Lower Limestone just coming in again, and that it thickens gradually to the eastward, while the intermediate grit diminishes.

At Middle Cave, on the north-west side of Malton, there is a quarry containing a band of rock which Mr. Hudleston considers to occupy the position of this bed. He says: "Here we perceive a very gritty limestone, 10 feet thick, presenting the lithological features of a passage-bed stone, and separating two oolites. Towards the base of this series there is a shell-bed charged with fossils, generally of large size. The bed is noted for large specimens of *Trigonia Meriani*, *Pecten intertextus*, and *Pholadomyæ*; otherwise the fauna is much the same as that of the Pickering *Trigonia*-beds."*

The following is the section† :—

	Ft.	In.
Oolite, rubbly and fragmentary, but increasing on the dip. ? Upper Oolite - - - - - - -	2	4
Alternations of hard bands of oolitic Calc-Grit, with large-grained softish Oolites. *Echinobrissus scutatus* - -	8	0
Two hard bands of gritty large-grained Oolite, separated by a red sand of variable thickness. The lower portion of the second block is a mass of shells, often of large size, in a sort of Passage-bed matrix. A splendid list is made from here, including *Am. plicatilis*, *Chemnitzia heddingtonensis*, *Lima læviuscula*, *Pecten imtertextus*, *Avicula ovalis*, *Gervillia aviculoides*, *Trigonia Meriani*, *Trigonia* (clavellate), *Cypricardia isocardina*, and fragments of *Thamnastræa*, *Rhabdophyllia* and numerous *Pholadomya* - - - -	3	0
Brashy line.		
Oolite, at base of quarry, without fossils. ? Lower Oolite -	6	0

The outcrop of this band might possibly be traced on either side of the valley north of the town if the rocks were better exposed.

South of Malton we have found no evidence whatever of this bed.

Upper Limestone and Coral Rag.

In the Filey section the Upper Limestone just comes in beneath the Drift, being represented by some 17 feet of brashy and broken oolitic limestone seen at the point and on the south side of the Carr Nase. These beds are not very fossiliferous, but Messrs. Blake and Hudleston mention *Cerithium limæforme*, *Actæonina*, *Echinobrissus scutatus*, and *Holectypus*, from them; *Exogyra nana*, *Ostrea duriuscula*, *Pecten articulatus*, and *Pecten vagans* are also common in the bottom bed.

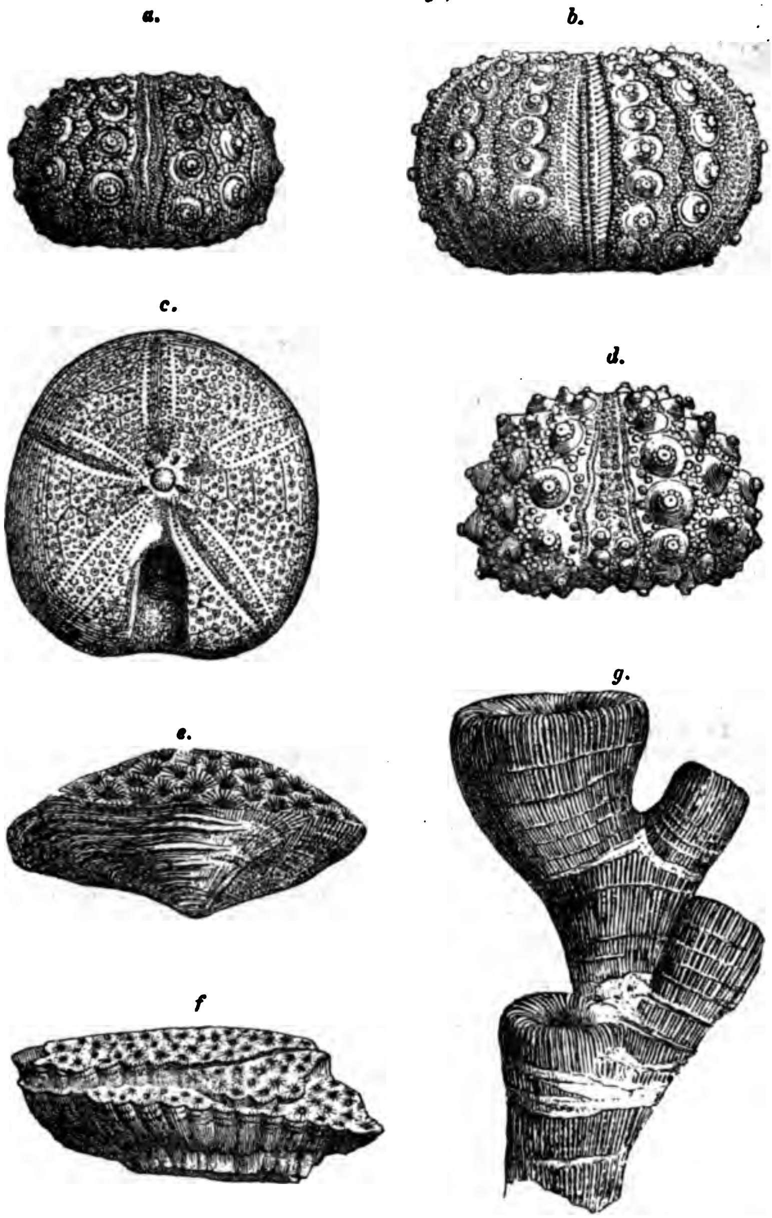
West of Filey these upper beds are entirely hidden by the Boulder Clay for a distance of 6 miles, although they were met with in the well of the Scarborough Waterworks, at Osgodby where the "Ragged Limestone commonly called Roundheads" evidently represents the Coral Rag with its characteristic large rounded lumps of *Thamnastræa concinna*.

* Quart. Journ. Geol. Soc., vol. xxxiii., p. 365.
† Proc. Geol. Assoc., vol. v., p. 429.

FIG. 18.

Fossils of the Corallian Rocks.

(Echinodermata and Corals from the Upper Limestone and Coral Rag.)



a. Cidaris florigemma, *Phil.* (after Wright) $\frac{2}{3}$; *b.* Cidaris Smithii, *Wr.* (after Wright) $\frac{2}{3}$; *c.* Echinobrissus scutatus, *Lam.* (after Wright) $1\frac{1}{3}$; *d.* Hemicidaris intermedia, *Flem.* (after Wright); *e.* Isastræa explanata, *Goldf.*, $\frac{2}{3}$; *f.* Thamnastræa arachnoides, *Park.*, $\frac{1}{2}$; *g.* Thecosmilia annularis, *Flem.* (corals after Milne-Eawards and Haime) $\frac{2}{3}$.

At Crossgates Quarry just west of Seamer Station, where the limestone first comes out from beneath the Drift, the rock has been worked for a number of years, and a considerable number of fossils have been obtained; in fact most of species in former times marked Scarborough have either come from this or Ayton Quarries. Messrs. Blake and Hudleston give the following detailed section of the beds here:—

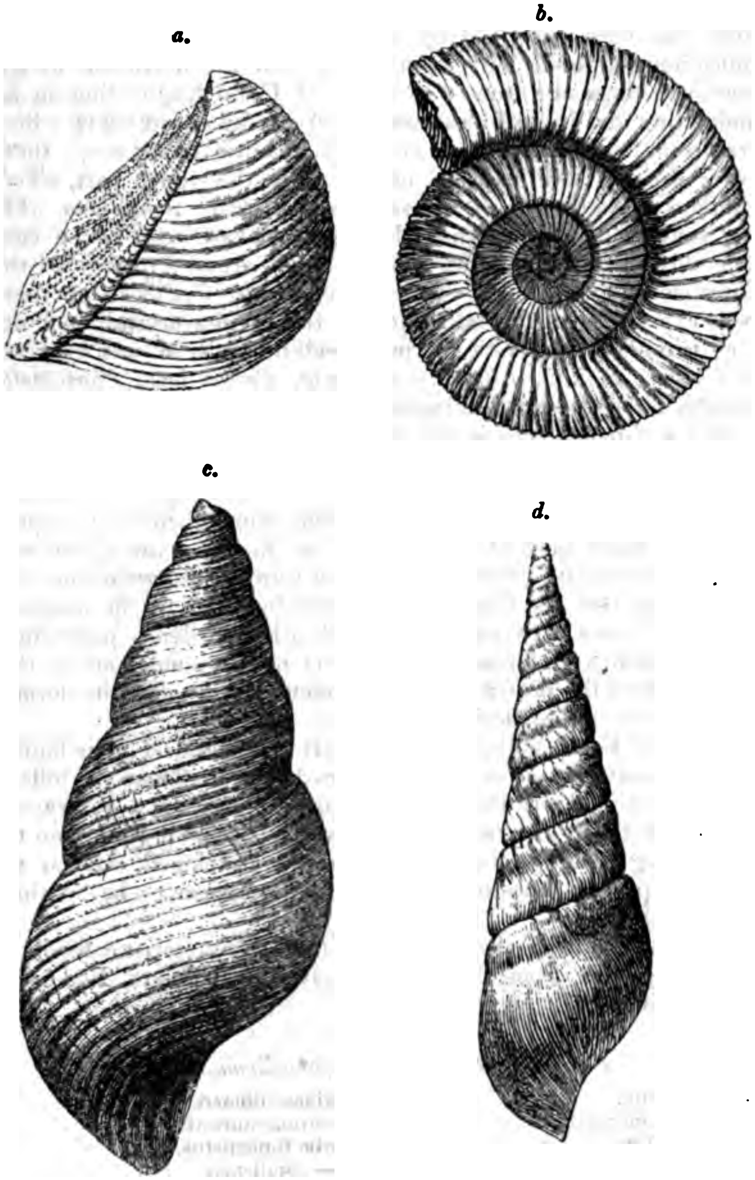
Section of the Crossgates Quarry, Seamer. **B. & H.**

		Ft.	In.
Coral Rag	Soil, broken rock, and boulders of *Thamnastræa concinna* (roundheads)	2	0
Oolites and Corals.	Oolite in a buff pasty matrix, with a bed of *Rhabdophyllia* at the base	3	0
	Oolite in a buff pasty matrix, with a shell-bed at the base *Nerinæa visurgis*, *Trigonia* (costate sp.) *Lucina*, sp. *Astarte duboisiana*, spines of *Cidaris Smithii*, and a few delicate fingers of *Rhabdophyllia*	2	8
	Thin clay parting	0	1
	Shell bed, partly oolitic. *Ammonites plicatilis*, *Nerinæa*, *Lucina*, *Astarte duboisiana*, many *Rhabdophyllia*, and stray fragments of *Thamnastræa* "Snake-bed"	1	4
	Indurated, cemented, large-sized pisolite, with an occasional coral. The "top-hard"	1	0
The Coral shell-bed.	The Coral shell-bed. A pale grey oolite, rather pasty; shells and corals very sparry. Fragments of *Thecosmilia*, often prostrate, and principally in the upper portion; *Rhabdophyllia*; a few lenticular masses of *Thamnastræa* towards the base; *Pecten fibrosus*, *Lima rigida*, *L. densipunctata*, *L. pectiniformis*, *Perna rugosa*, *Trichites*, *Arca pectinata*, spines of *Cidaris Smithii* very large; megalomorphic fauna. There is much comminuted shell in this bed. "The Bottom Hard."	2	0
Oolites	Rubbly pisolite, full of small *Exogyræ*	0	2
	Oolitic series, poor in shells, with an occasional brashy parting; excellent lime	6	6
	Rubbly pisolite, full of small *Exogyræ*; contains *Echinobrissus scutatus*, *Phasianella striata*, &c.; a constant parting	0	6
	Fine-grained oolites, making excellent lime; some of the upper portions of the beds are rather lumpy, owing to casts of *Phasianella striata*, and to nodules which may represent sponges. There is one moderately shelly bed. *Exogyra nana*, *Pecten fibrosus*, *Gervillia aviculoides*, *Trigonia*, *Lucina*, &c., to base of quarry	6	0
		25	3

Below this the beds are said to be fair limestones, but rather gritty.

Fig. 19.

Fossils from the Corallian Rocks.
(Upper Limestone and Coral Rag.)



a. Trigonia Meriani, *Ag*. (after Lycett) $\frac{1}{2}$; *b*. Ammonites plicatilis, *Sow*. (after d'Orbigny) $\frac{1}{3}$; *c*. Phasianella striata, *Sow* (original) $\frac{2}{3}$; *d*. Chemnitzia heddingtonensis, *Sow*. (original) $\frac{1}{2}$.

The Coral Rag and Limestone are frequently exposed along the foot of the hill to the west, and the outcrop of the crystalline beds of the Rag is very conspicuous. In the parishes of Ayton and Irton the Rag is extensively worked for roadstone, so that there are many exposures both in it and the associated limestone. One of the best known sections is that in the Ayton Quarry on the side of the road to Scarborough; which, being easily accessible, has been described by several authors, and from it large collections of fossils have been made. On the north side of the road here there are from 6 to 8 feet of Coral Rag resting on an undulating and irregular surface of soft brashy oolite, below which are from 20 to 30 feet of more solid oolitic limestones; these latter are not well exposed except quite the upper part, which contains a band full of *Nerinæa* and *Astarte duboisiana.* On the south side of the road the Rag beds are seen to be considerably thicker, and more like what they are in a quarry at the entrance to Yedmandale where there are 20 feet or so of these beds exposed. In this latter quarry the regular crystalline Coral Rag is much mixed with an intercoralline brash in which spines of *Cidaris Smithii, Littorina muricata, Pecten lens, Phasianella striata, Exogyra nana,* and other fossils are very abundant. These beds are also well seen in the gorge of the Derwent above Ayton, where there appears to be about 14 feet of Coral Rag resting on about 25 feet of oolitic limestone.* The relative thickness of these too, however, varies considerably in very short distances; so that, although there may be 20 feet of Coral Rag in some of the sections, it is doubtful whether it does not thin out altogether in other places; in fact the Coral Rag appears to stand up in irregular lumps or bosses between the oolitic brash and dense pasty limestones which were formed round them; in the same manner that coral reefs of the present day are surrounded by deposits formed from their own destruction.

West of Forge Valley the upper part of this limestone is hidden by the great terrace of sand and gravel which flanks the hills as far as Ruston, where the Coral Rag again appears in a quarry, and was cut into by the railway. Between here and Brompton the Coral Rag seems to be very extensively developed, even at the expense of the limestone, which does not appear to be so thick as about Seamer.

The following is the list of the more characteristic fossils of these Rag-beds from this area as given by Messrs. Blake and Hudleston:—

Fossils of the Seamer-Ayton-Brompton Rag.

Natica arguta.	Nerinæa Römeri.
Cerithium inornatum.	Littorina muricata.
—— limæforme.	Turbo funiculatus.
—— humbertinum.	—— corallensis.
Nerinæa fusiformis.	Trochus aytonensis.

* In the boring at Irton there were 120 feet of limestone passed through, but we have no means of ascertaining how much should be assigned to each subdivision.

Phasianella striata.
Trochotoma tornatilis.
Bulla Beaugrandi.
Ostrea duriuscula.
Exogyra nana.
Ostrea gregaria.
Anomia (smooth species).
Pecten articulatus.*
—— lens.
Hinnites tumidus.
Lima fragilis.
—— rudis.
—— rigida (small).
Perna mytiloides.
Arca quadrisulcata.
Cucullæa pectinata.
—— elongata.
Astarte aytonensis.
Myoconcha texta.
Lithodomus inclusus.
Modiola Lycetti.
Waldheimia margarita.*
Pseudodiadema versipora.
Cidaris Smithii.
Hemicidaris intermedia.
Rhabdocidaris Phillipsi.*
Thamnastræa concinna.

Between Brompton and Thornton Dale the lower beds, as we have noticed, are uplifted; and the Upper Limestone, being denuded off the summit of this arch, is entirely separated from that of the Pickering and Helmsley area. That it once existed over a portion of the intervening ground, even if the two were not absolutely connected, is probable from the fact of portions of the rock being preserved along the line of fault at Ebberston and Allerston.

Mr. Hudleston has observed that this stratigraphical break also coincides to a certain extent with a change in the palæontological character of these two areas. The outlier of these beds at Hackness, although separated by denudation from those just described, really belongs to that area, and therefore we take it before proceeding to the district about Pickering and beyond.

On the Hackness outlier two small patches of the Upper Limestone have been preserved which cap the hill just north of the Hall. The eastern of these consists of only the lower beds of Limestone, but the western one which is somewhat larger contains the full thickness of Limestone and Coral Rag, being covered at one spot by superior beds. It is not easy to estimate exactly the thickness of the beds here, but judging from the contour of the ground and allowing for the dip, there will be something like 40 feet of Limestone and Coral Rag. The Limestone is quarried on the right-hand side of the road going up to Silpho, where is the following section:—

Limestone Quarry, Bell Heads, Silpho. **B. & H.**

	Ft.	In.
Rubbly limestone fragments with occasional coral doggers in a reddish soil; abundance of *Phasianella striata* - -	1	0
Large-grained oolites in a bluish-grey calcareous paste. *P. striata, Chemnitzia, Astarte duboisiana, A. ovata,* &c. -	7	0
Strong band of *Thecosmilia*-rag—a kind of Coral shell-bed, showing a handsome arabesque of fossils. Spines of *Cidaris Smithii*, in great abundance, quantities of *Exogyra nana, Ostrea gregaria, Nerinæa*, sp., *Cerithium inornatum, Littorina muricata, Cylindrites Lhuidii* [?], *Arca quadrisulcata, A. pectinata* - - - - - - - -	2	9
Thick-bedded large-grained oolites, similar in character to those above, but rather softer; beds visible - - -	6	3
	17	0

* Species marked thus are revised from the later descriptions of Mr. Hudleston and other sources.

In correlating this section with that to the south these authors remark:—"The general accordance of this section with what we have already seen at Seamer leaves us no room to doubt that here we have the representative of what is usually known as the Coralline oolite of that locality. The band of *Thecosmilia*-rag in the oolite with so many of the same fossils, the presence of *Phasianella striata* and *Astarte duboisiana* in considerable numbers in the upper portion of the oolite, all point in the same direction, and go to prove the identity of this formation, making due allowance for variation, with that which immediately underlies the great stretch of Coral Rag between Seamer and Brompton."

On the west side of the road the ground rises to a greater height, and the Rag beds come on, being imperfectly seen here and there amongst the grass rising up in bosses which are perforated by the borings of *Lithodomi*.

Returning again to the main outcrop we find the Upper Limestone coming on again just west of Thornton Dale, where the lower beds are seen in a quarry between the two plantations at the top of the hill. The Limestone is here much thinner, and there does not appear to be any Rag, but from the want of a clear section, and the occurrence of one or two small faults, it is not easy to make out the limits of the Limestone, or to calculate its thickness. A little further west, however, the dry valley of Howl Dale cuts through these beds, and in a quarry at the southern end we get the following section:—

Quarry in Howl Dale, west of Hagg House. B. & H.

	Ft.	In.
Upper Calcareous Grit, very fossiliferous	6	0
Argillaceous marly layers	2	0
Dense ferruginous limestone in irregular lumps, containing *Natica*, *Nerinæa*, *Chemnitzia*, *Phasianella striata*, *Lima pectiniformis*, *Perna mytiloides*, *Arca quadrisulcata*, *Exogyra nana*, *Cidaris florigemma* (spines)	0	6
Oolite—few fossils	6	6
Dense and sometimes earthy limestones, with some oolitic granules—few fossils	12	0
Chemnitzia-limestones to base of quarry.		

Mr. Hudleston points out that this quarry is of interest as being the most easterly exposure of the Coral Rag with *Cidaris florigemma*, which he states does not occur in the Coral Rag of the Ayton-Brompton district.

The next exposure is the important one at Pickering, where these limestones have a thickness of about 50 feet, and have been extensively worked for a number of years both for lime burning and as a flux for melting the iron ore in the furnaces of North Yorkshire. The beds here are divisible into four or five subdivisions, most of which are tolerably constant, although they vary somewhat in thickness. Messrs. Blake and Hudleston have given a detailed account of this section; from which we take the following extracts:—

Generalized Section of the Upper Limestones at Pickering.
B. & H.

	Ft.	In.
Upper Calcareous Grit, with sandy and marly shales below, resting upon a thin bed full of *Ostreæ*.		
Bed of argillo-calcareous stone, locally termed "Throstler," wanting in places, or represented by a flaggy parting of a few inches - - - - - - - -	3	0
Top stone—a grey feruginous limestone, generally falsebedded, thicker on the west than on the east side - - -	5	0
Impure earthy limestones, known as "black posts," poor in fossils, but containing *Belemnites abbreviatus*, and towards the base *Am. varicostatus* - - - - -	10	0
Chemnitzia-limestones, compact and suboolitic. Shell-beds at intervals full of *Chemnitzia, Nerinæa; Astarte ovata* and other bivalves less numerous - - - - -	20	0
Variable limestones and pisolites, with shell-beds and nests of *Thamnastræa arachnoides* in the lower part; indications of Calc-Grit towards the base. Roadstones, &c. - -	13	0
Solid blocks of Calc-Grit and shell-beds below.		

The lowest of these beds forms a kind of passage into the Calc-Grit below, and is very variable in character. "It is sometimes divisible into as many as three minor blocks, and is a complete mixture of everything; corals may be noted both at the bottom and at the top, and possibly also in some parts of the central mass. Isolated groups of *Thamnastræa arachnoides* appear to have grown upon the top of the last bed of calc-grit; then came a shell-drift, with *Trigonia*-valves, *Astarte duboisiana* &c., then mixtures of calc-grit, and oolite, another string of shells, then some more decided oolite, with very fine *Nerinæa visurgis,* mixed with some more *Thamnastræa arachnoides.* Some parts contain so much coral as to present the appearance of a Coral Rag, but without the fauna of the true Rag."

In the upper part of this division there is a limestone with a marked band of pisolite; and above this are some exceedingly hard, dense, fine-grained limestones, which finally pass up into the more regular limestones with *Chemnitzia heddingtonensis.*

These latter, which form the main bulk of the Upper Limestones, are the beds which are principally quarried for lime. "*Chemnitzia heddingtonensis* and *Nerinæa* are tolerably abundant throughout, but especially so in a block towards the top of the series, which is evidently an old shell-bed. The sparry sections of *Chemnitzia,* in the white limestone or oolite, produce an appearance known to the workmen as 'rabbit-eye;' and these beds mark the termination for a while of the more fossiliferous limestones. This series at Pickering may be viewed on the whole as a mixture of creamy limestones full of oolitic grains with true oolites. On account of the great difficulty in extracting the fossils, the fauna cannot be determined with the same ease as that of the *Trigonia* beds. There are multitudes of shells in layers, but in such a compact matrix as to defy extraction. *Astarte ovata* and *Lucina aliena* are amongst the most plentiful of the bivalves; and *Trigoniæ* very like *T. perlata* occur sparingly."

The third division consists of flaggy, earthy limestones often very bituminous, and of little or no use for lime burning. These beds, on account of their comparatively dark colour, are called

by the workmen "black posts;" they have very much the appearance of having been formed by denudation from the purer limestones; and, as may be seen further west, appear to pass laterally into that class of rock.

Above the "black posts" is a bed of limestone of somewhat variable thickness, which is more ferruginous than the beds below, and contains a number of small shells such as *Ostrea, Nerinæa,* &c. This bed, which has received the name of "iron post," is the best suited for smelting purposes, and is on that account principally sent to the ironworks.

The highest part of the limestone at Pickering consists of a band of peculiar dense argillaceous limestone, locally known as "throstler." It is very hard, and has a sharp conchoidal fracture, but does not appear to contain any fossils. Mr. Hudleston is inclined to refer this bed to the Upper Calcareous Grit; but physically it is part of the limestone, and we do not see any more reason for separating it than some of the "black posts," which about Kirkby Moorside seem to be contemporaneous with, or even of later date than, the true Coral Rag. At present there is no palæontological evidence for so doing, and as the most marked change in mineral character is above this bed we have included it with the Limestone, the break between it and the soft shale and sandstone above being the only line that can be mapped.

To the north of Pickering the Upper Limestone spreads over a large area, and has been opened out in numerous small quarries, but there are no very good sections. There does not appear to be any Coral Rag in this direction, and the upper beds have a much more flaggy character than has been noticed elsewhere. In the low ground, however, to the west near Aislaby and Wrelton the Rag comes on again in force, showing clearly its very partial development.

In the gorge cut by the Seven at Sinnington these beds are well exposed in a quarry face on the left bank of the river, which shows the following details:—

Section of the Upper Limestones at Sinnington. **B. & H.**

		Ft.	In.
Coral Rag	Coral Rag with plenty of *Cidaris florigemma* in the lower block	13	0
	Rhabdophyllia-bed. The upper part is very full of small branches. This is the equivalent of the Coral shell-beds of other places	2	3
Coralline Oolite.	Comparatively unfossiliferous limestone, the lower portion impure and dirty	11	0
	Chemnitzia-limestones. The great shell-bed at the top is charged with *Chemnitzia heddingtonensis, Nerinæa,* sp., *Astarte ovata, Lucina Beanii,* &c. Noted also *Echinobrissus scutatus*	17	9
	Impure bluish limestones, with a line of scattered pisolite	6	0
		50	0

About a mile west of this is the little valley of the Hutton Beck, the bed of which being usually dry during the summer is very favourable for examination. A considerable thickness of Coral Rag and *Chemnitzia*-limestones are seen here, the details of which are given below :—

Section in Hutton Beck.

	Ft.	In.
Ochrey sandy beds with large *Ostrea bullata* - -	—	
Hard grey fossiliferous limestone with ringed *Serpula*, *Cladophyllia*, *Montlivaltia dispar*, *Cidaris florigemma*, *Cidaris Smithii*, *Ostrea bullata*, *Exogyra*, *Astarte ovata*, *Cerithium muricatum*, and *Littorina muricata* - -	3	8
Thick bed of denser limestone with *Pseudodiadema*, *Cidaris*, and *Belemnites* - - - - - -	2	8
Flaggy earthy beds, much used for walling, passing down into limestone, containing corals in some places - -	10	0
Coarsely oolitic bed with masses of *Cladophyllia* and *Rhabdophyllia*. *Trigonia* towards the base, which is irregularly bedded - - - - - -	2	6
Cherty fossiliferous limestone with *Chemnitzia heddingtonensis* - - - - - - - -	16	0

The beds here vary considerably in short distances, for in a quarry, which is about 100 yards from where the above section was measured, there does not appear to be any of the flaggy argillaceous limestone, which is the equivalent of the "black posts" of Pickering; but its place is taken by about 12 feet of irregular ragged limestone with *Cidaris florigemma* and branching corals; whereas just beyond, this rock comes on in full force attaining a thickness of 12 feet or so. In fact the Coral Rag seen in this quarry seems to be surrounded, or nearly surrounded, with these impure flaggy limestones; which, as we have suggested, may have been formed from the denudation of the purer beds, the Coral Rag now rising in bosses among the more stratified beds of limestone.

On the hill above there is also a good section in the quarry on Hutton Common near Waterswallows Cottage, where the beds are very fossiliferous, and are crowded with spines of *Cidaris florigemma* and branching Corals which stand out from the rock in fine relief.

Beyond Hutton Beck the outcrop of the Upper Limestone forms a narrow strip to the north of Kirkby Moorside, by Pockley to the neighbourhood of Helmsley. There are numerous quarries opened in the rock throughout this region, and it is also well exposed in the sides of the several gorges through which the moorland streams reach the Vale of Pickering. From these sections it is seen that the character of the rock keeps fairly uniform, there being generally from 10 to 14 feet of Coral Rag above the regular limestones, which latter at the base pass into blue and impure beds.

In a quarry near the roadside at Kirkdale are the remains of the famous Kirkdale Cave, in which were found the bones of no

less than 27 species of Mammalia and Birds. The cave, which has now been mostly quarried away, is situated about half way up the face of the quarry along an irregular line formed at the junction of the *Chemnitzia*-limestones with the more earthy limestones above; the upper surface of the *Chemnitzia*-limestones throughout this region is very hummocky, and is known to the quarrymen of Pickering and Hutton by the name of "hilly and holey;" on this irregular surface repose the more earthy limestones above with soft marly partings, which are easily worked away, and form a series of hollows that is the cave line throughout the district. It is at this horizon in the limestone that the numerous "swallows" or underground channels are formed, in which most of the streams in the neighbourhood lose a part or all of their water; and if the denudation of these valleys was carried 100 feet lower, it is probable that a fine series of caves would be exposed in this region.

In the neighbourhood of Helmsley the outcrop of the Limestone is broken by an east and west fault, having a downthrow to the south, which brings in a large spread of the rock over Duncombe Park to the west of the town, extending as far as the south end of the terrace overlooking Rievaulx. On the south side of the Rye it forms a steep bank along the river for some distance; it here appears to be getting more siliceous, as may be observed in several of the quarries.

Messrs. Blake and Hudleston describe the section here in the following words:—"In the quarry on the York road just out of Helmsley, a little above the 200-feet contour, about 20 feet of Rag beds are seen putting on a somewhat different lithological type. The stone is in strong blocks, and is a hard cherty (?) limestone with many flints, both in sheets and in tuberous masses: it is very rarely coralline. The beds are not so full of fossils as in the more typical Rag; but a considerable number of species may be noted, such as *Belemnites abbreviatus*, *Chemnitzia* (short variety of *heddingtonensis*?), *Natica clio*, *Nerinæa fasciata*, *Phasianella striata*, *Pecten vimineus*, *Trigonia* (large clavellate form), *Lucina aspera*, Buvig., *Terebratula insignis*, *Cidaris florigemma* (spines).

"This peculiar phase of the Rag is rather local; for on following the steep southern bank of the Rye in an easterly direction below Helmsley we find it gradually assuming a more coralline form. The exposures referred to consist of about 15 feet of dense creamy limestone, with a few corals and some of the usual fossils, resting on 7 feet of Rag with flints. Below this is a coral shell-bed with *Thamnastræa*, much *Thecosmilia*, *Rhabdophyllia*, *Hinnites velatus*, *Lima rigida*, *Lucina*, &c. This last is seen to rest on oolite a few feet above the level of the river."

West of the York road the rock may be traced along the steep bank facing Duncombe Park, and through the Park to Sproxton Quarry, where we have the following details:—

Section in Sproxton Quarry. B & H.

	Ft.	In.
Coral Rag, with *Lima pectiniformis*, *Pecten vimineus*, *Cidaris florigemma*, &c. - - - - - - -	4	0
Coral shell-bed containing corals, abundance of the spines of *Cidaris florigemma*, *Lithodomus inclusus*, *Lucina*, sp., together with *Nerinæa* and *Chemnitzia* - - -	1	6
Coralline oolite, compact and occasionally suboolitic limestones, containing numerous long univalves in the upper layers. Base of the limestone not seen - - -	26	0
	31	6

From the quarry in the Park close by the following fossils are mentioned :—*Chemnitzia*, *Littorina muricata*, *Perna mytiloides*, *Astarte rhomboidalis*, *Pecten vimineus*, and *Cidaris florigemma*.

From Sproxton Quarry the general direction of the outcrop, which is interrupted by the numerous dry valleys coming down from the Moor, turns south to Beacon House on the hill-top above Ampleforth College. At this point the outcrop trends east, and is quarried along the edge of the escarpment in several places. The Coral Rag portion of the Limestone is here well developed, and contains very fine *Thecosmilia* in position of growth, and *Isastræa*. The Limestone at this point attains its greatest elevation, about 690 feet, but rapidly falls away to the east, so that at Oswaldkirk it is only 300 feet, and at Nunnington cutting only 200 feet above sea-level; it however rises again in Cauklass Bank to the 300-feet contour.

The following is the section at Ampleforth Beacon :—

Section at Ampleforth Beacon Quarry (east end). B. & H.

	Ft.	In.
Red clay, with boulders and fragments of Upper Calcareous Grit filling up gaps and fissures in the limestone nothing to	10	0
Coral Rag—principally *Thamnastræa*; the upper portions are much chalcedonized; *Cidaris florigemma*, *Exogyra nana*, but few shells - - - nothing to	4	0
Chemnitzia-limstones, the equivalent of the Coralline oolite. about	18	0

"About 12 feet below the base of the Rag there is a splendid mass of shells occurring in the creamy limestone with buff granules, so characteristic of the Coralline oolite of this district," in which the following fossils were noted :—

Belemnites abbreviatus.
v.c. Chemnitzia heddingtonensis.
c. Nerinæa fasciata?
Cerithium muricatum.
r. Littorina muricata.
Cylindrites, sp. (small).
v.c. Exogyra nana.
Lima elliptica.
Perna mytiloides.
v.c. Lucina Beanii (? aliena).
c. —— oculus.
c. Astarte ovata (large, both valves).
Opis Phillipsi.
Pseudodiadema versipora.
Phasianella striata (in the bottom bed).

In a quarry about three-quarters of a mile to the east of this, on the edge of the escarpment, is the following section, showing a greater thickness of limestone :—

Section at Quarry on the top of Oswaldkirk Hagg. **B. & H.**

			Ft.	In.
Irregular patches of Upper Calcareous Grit, associated with a ferruginous clay filling hollows.				
Coral Rag; an old weathered surface exhibits a fine arabesque of *Thecosmilia* in an upright position, with very large specimens of *Chemnitzia*. *Exogyra nana, Pecten vimineus, Lima læviuscula, Lima pectiniformis*, and *Cidaris florigemma* (spines) are plentiful. *Thamnastræa arachnoides* and *Stylina tubulifera* noted - - - - -			6	0
Chemnitzia-limestones, the equivalent of the Coralline oolite, as follows :—	Ft.	In.		
. Creamy limestones with a few univalves, alternating with brownish hackly oolite and brash - - - -	6	0		
β. The principal shell-beds: *Chemnitzia heddingtonensis*, of all sizes in great profusion; *Nerinæa, Astarte ovata, Exogyra nana* plentiful; *Lucina oculus, Littorina muricata, Cerithium muricatum* less plentiful - - - -	6	0		
γ. White creamy limestones with buff-coloured granules; few shells - -	9	0		
			21	0
			27	0

At Oswaldkirk the limestone is quarried at several places, and has a thickness of about 50 feet; but beyond this it becomes truncated by the great east and west fault which brings in the Kimeridge Clay on the south, so that at Laysthorpe Lodge only a very few feet are seen, the greater part of the hillside being clay. In the hollow, however, through which the railway to Helmsley runs, the full thickness appears again, and the following sections are exposed in the railway and quarry close by; the limestone is here much shattered, and has large fissures probably caused by its proximity to the Stonegrave faults.

Sections in and near Nunnington Railway Cutting. **B. & H.**

	Ft.	In.
Surface accumulations and ferruginous gritty brash, forming the top of the Upper Calcareous Grit - - -	7	0
Upper Calcareous Grit in solid blocks - - - -	25	0
Coral Rag. Block coralline and sparry limestones, with *Thecosmilia* and *Thamnastræa*; many fossils - -	8	0
Coral shell-bed. A peculiar white oolite, exhibiting in some places reliefs marked by an occasional coral, spines of *Cidaris florigemma*, and more rarely of *Hemicidaris, Natica clio, Nerinæa, Chemnitzia* (short var. of *heddingtonensis*?), and numerous *Exogyra nana*; the upper part is the most fossiliferous - - - - - - - -	3	6
Unfossiliferous shivery oolites.		

In a limestone quarry a few yards to the west of the cutting there is already some difference.

	Ft.	In.
Upper Calcareous Grit (base only seen) - - -	4	0
Coral Rag, extremely fossiliferous - - - -	7	0
Coral shell-bed. An oolite with occasional spine of *Cidaris florigemma* - - - - - - - -	2	6
Coralline Oolite.		
Bed of oolite limestone - - - - - -	2	6
Suboolitic shelly bed, with *Gervillia aviculoides*, *Cerithium muricatum*, *Trigonia* (clavellate sp.), &c. - -	1	6
Shivery oolites, having the character of thick-bedded limestones, containing occasional specimens of *Ammonites plicatilis*, but not very rich in shells.		

Referring to this district Messrs. Blake and Hudleston further observe: "The Coral Rag of the Oswaldkirk district, especially about Nunnington, is rendered very interesting by the quantity of *Thecosmilia* which it contains, and also by the profusion of spines of *Cidaris florigemma*. The varieties of Coral are perhaps more considerable than is generally the case in Yorkshire, as we frequently meet with *Montlivaltia dispar* and *Stylina tubulifera*, besides the more common reef-building forms: in these respects it differs much from the *Cidaris-Smithii* Rag of Seamer-Brompton, chiefly remarkable for *Thamnastræa concinna* and *Rhabdophyllia*.

The principal fossils noted are :—

Natica clio.
Chemnitzia (short form of heddingtonensis).
Nerinæa fasciata.
Littorina muricata.
Ostrea gregaria.
—— moreana.
Exogyra nana.
Pecten vimineus.
Lima pectiniformis.
Modiola inclusa.
Cidaris florigemma.
Hemicidaris intermedia.
Stomechinus gyratus.
Glypticus hieroglyphicus.

At Stonegrave the Limestone forms a large spread on the hilltop, and is also quarried in the bank-side at the village and at the side of the road going up to Nunnington. The stratigraphy is here exceedingly obscure, but it is probable that the outcrop of the Limestone is repeated by a fault in the hill-side, otherwise the thickness would be too great as we have limestone nearly at the 175-feet contour and also at the 300-feet, which would give more than 100 feet, or what is twice the usual thickness in this district.

A noticeable fact in the beds about here is the great abundance of corals, *Thamnastræa*, *Thecosmilia*, and *Cladophyllia*; there is also a peculiar shaly band about a foot thick, which is exposed in the quarry between the two lanes south of Ness very near the end of this promontory. The upper part of the limestone is fine-grained and remarkable for the abundance of Gasteropoda it contains. Messrs. Blake and Hudleston mention the following fossils from here :—

Cerithium inornatum.
—— limæforme.
—— muricatum.
—— sp. (cf. virdunense).
Phasianella striata (juv.).
Rissoa? sp.
Chemnitzia.
Nerinæa.
Astarte ovata.
Trigonia Hudlestoni.

At the base of the Limestone in this district, that is from Ampleforth to Cauklass, there is a peculiar band of rock consisting of impure gritty beds with oolitic grains; it has a thickness of only a few feet, and constitutes a sort of passage-bed from the Calcareous Grit into the limestone above. Stratigraphically this bed is at a higher horizon than the Passage Beds previously mentioned at the base of the Lower Limestone, as can be seen by following up the road from Ampleforth village to Beacon House, which passes successively over the Lower Calcareous Grit, the cherty representative of the Lower Limestone and a considerable thickness of Middle Calcareous Grit before coming to it. This band of rock is best seen below the old tree in Oswaldkirk Bank and close to the Inn at Stonegrave; it also crops out generally at the base of the Limestone throughout the Howardian Hills, although it is too thin to be shown on the map. It has but few fossils—a stray *Chemnitzia*, *Avicula ovalis*, and *Opis Phillipsi*, all small, being the only species that are mentioned from it.

In the great faulted trough along the Coxwold-Gilling valley the Upper Limestone is only seen in the quarry at Snape Hill, near Kilburn, where a few feet of it are exposed in the bottom of the quarry. It is here covered by from 30 to 40 feet of higher beds belonging to the Upper Calcareous Grit, which roll over into the large fault immediately to the north, so that there is no natural outcrop. Along the south foot of the hill, where we should expect this rock to come out, the ground is so thickly covered with Boulder Clay as to hide all traces of it. The limestone, which has been preserved in this isolated section, is very crystalline with *Thecosmilia annularis*, *Ostrea gregaria*, and spines of *Cidaris florigemma*, and although there is only a thickness of about 4 ft. 6 in. to be seen, it is a true Coral Rag very similar to that just described at Beacon House above Ampleforth, nearly six miles to the east.

Throughout the Howardian Hills the Upper Limestone forms a more or less continuous outcrop along their northern flank from Gilling to Malton; while south of this there is a second line of outcrop brought in by large faults, which is best exposed at Coneysthorpe, and between Langton and Grimston, although there are indications of it at other places.

At Gilling the Limestone first comes on, capping the hill south-east of that village. It consists principally of coarse, pisolitic limestone resting on finer beds; further east as the strata fall with the dip a greater thickness is preserved, and sections in the Rag are numerous. In the neighbourhood of Cawton there are about 10 feet of Coral Rag, in which *Thecosmilia* is very abundant; the spines of *Cidaris florigemma* here are also remarkable for their large size.

On the south side of this hill near Sike Gate there is a shallow quarry, about which there is much uncertainty. Messrs. Blake and Hudleston, on palæontological grounds, consider that the beds here belong to the Rag subdivision, or at any rate represent a high position in the Limestone. The stratigraphical evidence

is certainly opposed to this theory, for the Calcareous Grit crops out nearly at the same level in the bank to the south within 100 yards of this quarry, and there is no appearance of a fault between the two, although in such disturbed ground as this it is possible there may be an east and west dislocation at this place. The beds consist, in the upper part, of rather rubbly oolites with brashy partings; those below being coarser and more massive. The following is the account given by Messrs. Blake and Hudleston of these beds:—"The upper portions [three bands of oolite with brashy partings] constitute one subdivision, and are remarkable for the number of urchins. *Collyrites bicordatus* (large form, similar to the one at Hildenley and North Grimston) occurs. *Holectypus depressus* and *Echinobrissus scutatus* are very plentiful; spines of *Hemicidaris intermedia* not uncommon, and more rarely *Pseudodiadema hemisphæricum.* Spines of *Cidaris florigemma* were observed in stone piled up by the side of the kiln. In these beds also occur *Pholadomya æqualis?*, *Myacites recurva, Goniomya v-scripta,* and in the brash at the bottom occasional specimens of *Am. plicatilis.* The lower hard band contains many univalves—*Natica clio* or *corallina, Littorina pulcherrima,* Dollf., and *Chemnitzia* sp. *Lucina aspera,* Buvig., a shell generally indicative of a high position, is also very abundant; and in the lowest bed of all are many specimens of *Ammonites plicatilis,* and of *A. cordatus* and *A. vertebralis,* presenting singular varieties, of which we have figured one as *A. cawtonensis.* The rest of the fossils obtained from this quarry, but the exact position not noted, are:—

Belemnites abbreviatus.
Ammonites, sp. (cf. perarmatus) (remarkable form).
Purpuroidea nodulata.
Pleurotomaria reticulata.
Exogyra nana.
Gryphæa dilatata
Pecten, sp.
—— vimineus.
Lima rigida.
Modiola subæquiplicata.
Trigonia (narrow costate form).
Astarte ovata.
Protocardium isocardioides.
Goniomya literata.
Terebratula insignis.
Pygaster umbrella.
Clypeus or Pygurus, sp.

From the above account it will be seen that the fauna on the whole indicate rather a high position for this quarry, but it is probable that the lower part of the limestone is absent, and that these beds are really not very far from the top of the Calcareous Grit; at any rate the limestones below the Coral Rag are not nearly so thick here as they are either to the north or east.

On the opposite side of the little valley south of Hovingham Spa the beds are thrown up by a fault, so that the Coral Rag crops out along the summit of the ridge forming the western part of Hovingham Park. The beds below are, on the south side, softer and more homogeneous; and have been worked in tunnels in the quarry near the bridge as a freestone, in this respect resembling some of the beds at Hildenley to be mentioned presently. On the north side of this ridge, about 200 yards from this, there is a second quarry which exposes about 17 feet of oolitic limestone passing down into impure beds similar to those noticed on the

opposite side of the Gilling Valley; these beds therefore represent the base of the limestone, and as the Rag is seen in the hill only a short distance above, it is evident that there cannot be much of the homogeneous rock on this side of the hill. Again further east, in the quarry at Hovingham, there is about 25 feet of oolite with Rag above, without a trace of this class of rock, so that its extent must be very limited.

Section at Hovingham Lime-quarry. **B. & H.**

	Feet.
Broken fissile Rag - - - - - - -	4–5
Hard coral limestones in massive undulating beds with rounded terminations - - - - - - -	14–15
Coral shell-bed; not constant as such. The lower portion, which has the most shells, contains *Rhabdophyllia*; the upper *Thecosmilia*, enormous spines of *Cidaris florigemma*, *Exogyra nana*, *Astarte*, *Glypticus hieroglyphicus*, and broken shells - - - - - - - - -	2–3
Softish oolites, very unfossiliferous.	

East of Hovingham the Coral Rag is well developed along the foot of the hill as far as Slingsby, while the oolitic beds crop out higher up the hill, but there are no quarries of particular note. At Slingsby there is a fine face of rock from which the branching stems of *Thecosmilia* and the spines of *Cidaris florigemma* have weathered out in relief, the latter being as is usual in this district of great size.

Between Slingsby and Barton we lose all trace of the Coral Rag, and the limestones below become poorer in fossils; in fact it is probable, as we mentioned previously, that the beds at the latter place belong to the subdivision of the Lower Limestones. At Appleton we have seen the strata are so much upheaved as to bring up the Lower Calcareous Grit, beyond which they gradually decline so that the Limestone comes in again; and, although it is probable there is a thin covering of Upper Limestone over much of the intervening country, it is not till we reach the town of Malton that any great thickness of that rock occurs. Here the Limestones have been extensively worked for a number of years, and several quarries have been opened in the rock. The principal of these is the large quarry at the cross-roads on Peasey Hills just north of the town, which shows a thickness of from 30 to 40 feet of limestone composed of three classes of rock—Coral Rag on the top; pure white oolites below, containing a somewhat scanty fauna, but which seems to belong partly to the Rag and partly to the Oolites; while below this is the regular *Chemnitzia*-limestone, which is very fossiliferous in the upper part.

Messrs. Blake and Hudleston give the following list of fossils from the Oolites of the Malton district, exclusive of those occurring in a Rag matrix only. Species indicative of a low and high position are shown by the letters *l* and *h* respectively.

Fossils from the Oolites of the Malton district, exclusive of those in a Rag matrix.

Reptilia.
Pisces.
c. Belemnites abbreviatus, *Mill.*
—— hastatus, *Montf.*
—— sp.
h. Ammonites varicostatus, *Buckl.*
c. —— plicatilis, *Sow.*
—— cordatus, *Sow.*
v.c. Chemnitzia heddingtonensis, *Sow.*
l. Cerithium muricatum, *Sow.*
c.h. Nerinæa Römeri, *Goldf.**
—— pseudovisurgis, *Hud.**
Phasianella striata, *Sow.*
Pleurotomaria reticulata, *Sow.*
l. Cylindrites elongatus, *Phil.*
Actæon retusus, *Phil.**
Ostrea solitaria, *Phil.*
l. Gryphæa dilatata, *Sow.*
Exogyra nana, *Sow.*
Anomia.
h. Pecten articulatus, *Schlot.** (P. vimineus, *Sow.*).
—— lens, *Sow.*
—— demissus, *Sow.*
h. —— intertextus, *Röm.* (cancellatus, *Bean.*)
—— inæquicostatus, *Phil.*
—— fibrosus, *Sow.*
c. Lima læviuscula, *Sow.*
—— rigida, *Sow.*
—— elliptica, *Whit.*
h. —— pectinformis, *Schlot.*
l. Avicula ovalis, *Phil.*
l. Gervillia aviculoides, *Sow.*
l. Perna mytiloides, *Lam.*
—— sp. n. (York Museum).
Trichites Plotii, *Llhwyd.*
Mytilus pectinatus, *Sow.*
Mytilus jurensis, *Merian.*
Cucullæa corallina, *Damon.*
Trigonia Meriani, *Ag.*
—— perlata, *Ag.*
—— sp.
h. Protocardium isocardioides, *Bl. & H.* (? lobatum *Phil.*).
v.c. Lucina aliena, *Phil.*
—— oculus, *Bl. & H.*
—— ampliata, *Phil.*
Corbicella* Buvignieri, *Desh.*
—— decussata, *Buvig.*
—— lævis, *Sow.*
—— uniformis, *Bean.*
Tancredia curtansata, *Phil.*
Unicardium plenum, *Bl. & H.*
Cyprina corallina, *d'Orb.*
c.h. Astarte ovata, *Smith.*
Opis Phillipsi, *Morris.*
l. Sowerbya triangularis, *Phil.*
Quenstedtia lævigata, *Phil.*
Panopæa gigantea, *Buvig.*
Anatina or Solemya, sp.
l. Pholadomya paucicosta, *Röm.*
Myacites decurtatus, *Phil.*
—— recurvus, *Phil.*
—— sp.
Goniomya literata, *Sow.*
Gresslya peregrina, *Phil.*
Pygurus pentagonalis, *Phil.*
—— Hausmanni, *K. & D.*
—— Phillipsii, *Wright.*
Pygaster umbrella, *Ag.*
l. Echinobrissus scutatus, *Lam.*
l. Holectypus depressus, *Lam.*
Carpolithes plenus, *Phil.* ?
—— conicus, *L. & H.*
Araucarites Hudlestoni, *Carr.*

At Hildenley a small patch of this Limestone has been let down by a cross-fault, so as to crop out for some distance along the bank above the Hall. Although a good deal of oolitic limestone and some Coral Rag is seen in this neighbourhood, the majority of the rock is of a very peculiar character, and from the obscure stratigraphy just here its relation to the other beds is not very clear. It is possible this limestone may be the result of the denudation of the Rag, and to a certain extent occupy the place of that formation as suggested by Messrs. Blake and Hudleston, who give the following account of it: "In the quarry on Hildenley Heights there is a peculiar limestone with a marked Rag or Upper Corallian fauna, the only trace of coral now remaining being some remarkable cavities in the lower side of

* Species marked thus are revised from Mr. Hudleston's later descriptions and other sources. The letters *l* and *h* signify that the species are usually indicative of a low or high position respectively.

some of the beds, which represent places where branches of corals have been, and where they undoubtedly have grown. The stone is extremely fine in the grain, is said to contain about 95 per cent. of lime carbonate, and has the appearance of having been deposited as fine mud within a tranquil lagoon or bay. It rests upon oolite, and is supposed, by Sir Charles Strickland, to be flanked also by that class of rock. The stone, from its homogeneous character, is valuable for building, and especially for carving, with the exception of those beds which contain a small *Ostrea.* The valves of these are partly silicified, and the chisels of the workmen thereby spoilt. It is evident that there is a considerable amount of chalcedonic silica in these beds; and the action which this silica has undergone is not without its effect upon the fossils: indeed the variety of fossilization is remarkable. The fauna indicates a high position in the series; and some of the most characteristic fossils are those of the Upper Calcareous Grit of other places, as *Modiola cancellata*, Röm., and *Lucina aspera*, Buvig.

"The following partial list will serve to show the character:—

Ammonites varicostatus.	Gryphæa, (large sp.)
Natica grandis.	Exogyra nana.
—— clio.	Pygurus pentagonalis.
Lucina aspera.	Collyrites bicordatus (large).
Protocardium isocardioides.	Pseudodiadema hemisphæricum.
Arca pectinata.	Hemicidaris intermedia.
Modiola cancellata.	Cidaris florigemma.

Along the second line of outcrop, south of the range just described, there is a faulted outlier of the Upper Limestone at Coneysthorpe, brought in by a large east and west dislocation at the foot of the main escarpment. The limestone here, which has a sharp dip into the fault, is well exposed in a quarry behind the village, where the following fossils were collected:—

Cidaris florigemma.	Ammonites biplex.
Pseudodiadema hemisphæricum.	—— trifidus.
Gryphæa dilatata.	—— achilles.
Pecten vagans.	—— plicatilis.
Ammonites perarmatus.	

Further east the basement beds of the Limestones are just caught in against the faults at Gaterley, at Nod Hill, and at one or two places in the low ground near Langton village; but there is not much of the rock seen at any of these places, and the sections are of little importance except as proving the shattered state of the stratification.

The main outcrop in this region is that forming the great spread on Langton Wold, and extending thence to Settrington and North Grimston. Throughout this district there is a great development of the Coral Rag, which covers most of the surface of Langton Wold; while the Oolite crops out below, principally on the north side in the low escarpment facing Malton. The quarries along this bank are mostly in oolitic limestone with a thin covering of Rag; which latter, rising with the inclination of the ground,

keeps the surface over the greater part of the hill, till it reaches the crest of the ridge overlooking Langton, where it attains its greatest thickness. At this point the beds turn sharply over to the south, and plunge down into the fault ranging along the foot of these hills. Along this southern edge of the outcrop Corals and the spines of *Cidaris florigemma* are very abundant, the rock being not unlike what it is in the quarries at North Grimston, where a much greater thickness of beds is exposed.

In the remarkable hill at North Grimston, where the strata are brought up by the large fault in Nine Spring Dale, we have a good opportunity of examining these beds and estimating their thickness. On the north side of this hill the base of the Limestone is seen just above the road going up Nine Spring Dale, and also in the quarry below Grimston Hill House, which is at about the 275 contour-line; while the house itself, which stands close to the top of the rock, is at the 375 contour-line, consequently there is about 100 feet of limestone in this bank. Nearly the full thickness of these beds is exposed in the large quarries at the railway, and above the road on the south side of the hill. Messrs. Blake and Hudleston, who also estimate the thickness of the Upper Limestones at about 100 feet, give the following detailed account of this section:—

Section at North Grimston. **B. & H.**

		FT.	IN.
Coral Rag -	2. Coral Rag, "North Grimston Limestone," - - - - about	40	0
	3. Marly Oolites, with an occasional coral band or hard limestone, the mammillated-Urchin series, say - - -	25	0
Coralline oolite and passage-beds.	4. Drab-coloured marly oolites, becoming very earthy towards the base: full of *Echinobrissus scutatus*, the equivalent of the Coralline oolite of other districts, say	30	0
	4^1. Passage-beds - - - 6 0		
	Total limestone	95	0

The principal feature in this section is the great expansion of the Coral Rag, which is here many times thicker than anywhere else along the whole line of outcrop we have been describing. Messrs. Blake and Hudleston state there is no such display of this class of rock elsewhere in England. They give the following account of the several divisions in this section:—

"*The Coralline Oolite.*—The true character of the lower half of this series is not very clear. It consists of harder and softer layers of brownish marly paste with oolitic granules, in this respect somewhat resembling the overlying series, which on palæontological grounds is included with the Rag: *Echinobrissus scutatus* is the prevailing fossil. There is a small opening towards the base of the escarpment under Grimston Hill House, where

the harder beds are extracted for road-stone. Few fossils other than *Ech. scutatus* were noted here; but the lower beds contain stray specimens of *Chemnitzia heddingtonensis.* Towards the middle of this quarry a well-preserved spine of *Cidaris florigemma* was noted. The latter fact is remarkable, as this urchin is very characteristic of the Rag; nevertheless a stray specimen has been noted as low as the *Trigonia*-beds of Sinnington."

The Mammillated-Urchin series is best exposed at the west end of the railway quarry. These beds "are seen to consist of flattened buff-coloured granules in a buff or drab-coloured marl; and sometimes the marl or paste is devoid, or nearly so, of any granules. They are divided occasionally by beds of hard compact limestone having partially the features of the Rag, and containing a few corals, many spines of *Cidaris florigemma,* and small muricated univalves: one of these hard bands, towards the top of the series, has a thickness of 2 ft. 6 in., and exhibits a fine arabesque of shells, such as are usually associated with a Rag-fauna. Throughout the series, and especially towards the upper part, a profusion of the spines of urchins may be noted, and the tests of many are from time to time discovered. *Pseudodiadema hemisphæricum* is especially abundant, and may be called the North-Grimston Urchin *par excellence. Cidaris Smithii, Cid. florigemma, Hemicidaris intermedia* also occur, the latter frequently. *Collyrites bicordatus* and *Pygaster umbrella* are also quoted from here; and *Echinobrissus scutatus,* which swarms in the lower beds, cannot fail to put in an appearance. The remains of the Mollusca in the softer beds are not usually in good condition. Cordate Ammonites, *Naticæ, Pleurotomariæ, Alariæ,* and one specimen of *Terebratula insignis* have to our knowledge been obtained from here."

The North-Grimston Limestone, or *Coral Rag proper,* which is seen in the upper quarry, consists of the following subdivisions:—

Upper Quarry, North Grimston. **B. & H.**

	Ft.	In.
Buff-coloured limestones with yellowish markings; beds of white stone, seldom hard and crystalline like the series below. Indications of corals moderate: flints rare. Spines of *Cidaris florigemma* less plentiful. *C. Smithii* and *Hemicidaris intermedia* numerous. Beds less shelly than lower series, but contain a fair assemblage of some of the Rag-fossils, *Nerinæa, Littorina pulcherrima, Opis,* &c., along with *Pentacrinites* and *Apiocrinus* - - - about	20	0
Soft yellowish brash with *Ammonites varicostatus* - -	0	4
White sparry and compact limestones in strong blocks, which become largely charged with flint, especially about 6 ft. above the base of the series. Beds full of fossils: fauna megalomorphic - - - - - - -	17	0
Urchin series.		

South of North Grimston the Upper Limestones thin out very rapidly, and in the Birdsall country, where these beds should come out again, there is scarcely a trace of any limestone. In this neighbourhood the Cement-stone, the equivalent of the Upper

Calcareous Grit, rests directly on the Lower Calcareous Grit, the only indication of these beds being a little impure limestone with oolitic grains at Toft House.

Messrs. Blake and Hudleston give the following list of fossils from these beds :—

Fossils from the Rag, or Upper Corallian of the Langton-Grimston District.

Belemnites abbreviatus, *Mill.*
Nautilus aganiticus, *Schlot.*
Ammonites varicostatus, *Buckl.*
—— alternans, *Von Buch.*
—— vertebralis, *Sow.*
Purpuroidea nodulata, *Y. & B.*
Natica buccinoidea, *Hud.**
—— clymenia, *d'Orb.**
—— clytia, *d'Orb.**
Chemnitzia heddingtonensis, *Sow.*, var.
—— pollux, *d'Orb.*
—— langtonensis, *Bl. & H.*
Nerinæa moreana, *d'Orb.**
—— Römeri, *Goldf.**
Littorina muricata, *Sow.*
—— —— var. pulcherrima, *Dollf.*
Nerita, sp. n.
Neritopsis Guerrei, *Heb. & Desl.*
—— decussata, *Münst.**
Trochus, sp.
Turbo corallensis, *Buvig.*
—— erinus, *d'Orb.**
—— Pellati, *De Loriol.**
Pleurotomaria reticulata, *Sow.*
—— Agassizii, *Münst.**
Trochotoma tornatilis, *Phil.*
Alaria, sp. (cf. tridactyla, *Buvig.*).
Ostrea duriuscula, *Phil.*
Exogyra nana, *Sow.*
—— sp.
Ostrea gregaria, *Sow.*
Anomia radiata, *Phil.*
Plicatula sp. (cf. fistulosa, *L. & M.*)
Pecten vimineus, *Sow.*
—— inæquicostatus, *Phil.*
—— intertextus, *Röm.*
Pecten lens, *Sow.*
Hinnites sp. n. (very large).
Lima læviuscula, *Sow.*, var.
—— rigida, *Sow.*
—— pectiniformis, *Schlot.*
—— rudis, *Sow.*
—— elliptica, *Whit.?* var.
—— subantiquata, *Röm.*
Avicula ædilignensis, *Bl.*
Trichites Plotii, *Llhwyd.*
Mytilus ungulatus, *Y. & B.*
Modiola inclusa, *Phil.*
Arca quadrisulcata, *Sow.*
—— pectinata, *Phil.*
Cucullæa elongata, *Phil.*
Trigonia (costate sp.)
Protocardium isocardioides, *Bl. & H.*
Astarte ovata, *Smith.*
—— rhomboidalis, *Phil.*
Opis virdunensis, *Buvig.*
—— lunulata, *Röm.*
Opis Phillipsi, *Morris.*
Panopæa gigantea, *Buvig.*
Homomya crassiuscula, *L. & M.*
Goniomya v-scripta, *Sow.*
Terebratula insignis, *Schüb.*, var. maltonensis, *Oppel.*
Cidaris florigemma, *Phil.*
—— Smithii, *Wright.*
Hemicidaris intermedia, *Fleming.*
Pseudodiadema hemisphæricum, *Ag.*
Collyrites bicordata, *Leske.*
Pygaster umbrella, *Ag.*
Echinobrissus scutatus, *Lam.*
Pentacrinus, sp.
Apiocrinus, sp.

UPPER CALCAREOUS GRIT.

Origin of the name.—Both William Smith and Prof. Phillips recognised the existence of this bed, and assigned to it its correct position in most places; although, from the division between the Upper and Lower Limestones not having been made out at that time, the sandstone at Wass was confused with it. Prof. Phillips, in his description of the north side of the Vale of Pickering, alludes to the Kimeridge Clay as lying on "a brown sandy stone," so that apparently the term Upper Calcareous Grit was not used at so early a date as this (1828); but it must have

* Species marked thus are revised from Mr. Hudleston's later descriptions.

been adopted almost immediately afterwards, as in the "Illustrations of the Geology of Yorkshire," published next year (1829), the name is applied to this subdivision, which is apparently the first time it occurs.

Along its northern outcrop the lithological character of the Upper Calcareous Grit is that of a soft, rubbly, ferruginous sandstone of a brownish-red colour. In texture the rock has a peculiar sharp gritty feel, as if every particle of lime had been dissolved out, not unlike that of the Kellaways Rock in exposed situations. The rock, especially in the neighbourhood of Helmsley and the western end of the Vale, contains large calciferous doggers very similar to those of the Lower Calcareous Grit. It is also very full of those branching tuberous masses which are so common in that bed. These in the Pickering quarries have frequently become washed out from the rock, and have fallen into fissures in the limestones, where they have been mistaken for bones. In the neighbourhood of Pickering, where this rock is locally known as "the red rock," the lower beds are shaly, and contain a remarkable layer of *Ostrea bullata* at the base.

Along the southern edge of the basin the rocks, which represent the Upper Calcareous Grit in time, present a very different aspect. Throughout the Howardian Hills this subdivision, although it is only seen at the two extremities of the range, consists of a peculiar calcareo-argillaceous rock locally known as "Cement-stone."

On the east side of the anticlinal axis at Allerston, which has separated the upper portion of the Middle Oolites into two distinct areas, the Upper Calcareous Grit is everywhere, excepting on the small outlier at Hackness, either faulted out or covered up by superficial beds, so that there is no natural outcrop of the rock anywhere in this district. In fact, until the boring, lately made for the Scarborough Waterworks at Irton, was put down, it was unknown whether the Kimeridge Clay rested directly on the limestone or not. In this boring 46 ft. 6 in. of sandstone were passed through beneath the shales of the Kimeridge Clay before reaching the limestone with *Cidaris*, and in a boring lately made at Filey (1891) this rock was found to have a thickness of 45 feet. Thus we learn that the Upper Calcareous Grit, although not a trace of the rock is to be seen at the surface, is fully as thick at this its eastern limit as it is anywhere else throughout its entire outcrop.*

On the outlier at Hackness the Upper Calcareous Grit is only very imperfectly seen, but it is apparent there cannot be any very great thickness of the rock. The only evidence here is that derived from the fragments scattered about the fields on the high ground above the limestone of Loffeyhead Heights south of Silpho. From this place Messrs. Blake and Hudleston mention

* This only refers of course to the Upper Calcareous Grit in its normal condition; the Cement-stone and calcareous clays which take the place of this bed in the neighbourhood of North Grimston are much thicker.

the following fossils :—*Ammonites biplex, Pecten midas, Avicula ovalis,* var. *obliqua,* two species of *Lucina, Thracia, Pleuromya,* &c.

In the Pickering-Helmsley area the Upper Calcareous Grit first comes in on the high ground west of Thornton Dale, where it covers most of the surface between there and Pickering, being frequently exposed wherever the soil has been removed. In the quarry near Hagg House, at the low end of Howl Dale, there are about 8 feet of these beds exposed, the lower 2 feet of which resting on the limestone are very shaly. Further west in the Pickering quarries, where there are about 20 feet of this class of rock, the shaly beds have increased to nearly 10 feet; below which is the peculiar and irregular band of grey, argillaceous, smooth, hard limestone which Messrs. Blake and Hudleston include with the Upper Calcareous Grit, although, as we have already mentioned, there does not seem to be much reason for so doing, the principal physical break being at the top of this band not below it.

The following are the list of fossils mentioned from this locality :—

Fossils of the Upper Calcareous Grit, Pickering. **B. & H.**

r.	Belemnites nitidus.
c.	Ammonites, sp. (cf. achilles).
c.	—— "biplex."
	—— alternans.
	Chemnitzia, sp.
	Patella mosensis.
	Exogyra nana.
c.	Ostrea bullata.
	Avicula ovalis, var. obliqua.
	Perna mytiloides.
c.	Pecten midas.
	—— demissus.
	Modiola cancellata (dwarf).
	Trigonia Voltzii.
	Protocardium (small sp.).
v.c.	Lucina aspera.
	—— substriata.
	? Corbicella.
	Goniomya literata.
	—— v-scripta.
c.	Pleuromya tellina.
c.	—— Voltzii.
	Myacites, &c. (numerous).
	Thracia, sp. (cf. depressa).
	Discina elevata.

At Sinnington the Upper Calcareous Grit is exposed in the top of the bank above the old quarry along the side of the river and in the lane just north of the village. At the south end of this quarry the grit is let down by a small fault so that the limestones and sandstones are seen side by side. The best section, however, in this neighbourhood is that in Hutton Beck, close to where the road and railway cross this stream. Here a continuous section from the Limestone through the Calcareous Grit into the Kimeridge Clay, showing almost a gradation from one into the other, may be seen.

Section measured in Hutton Beck.

	Ft.	In.
Black Shale crowded in places with *Vermicularia* - -		
Grey mottled sandy beds - - - - -	2	6
Soft reddish sandstone with fucoids - - - -	4	0
Ochrey sandy beds containing *Goniomya v-scripta, Ammonites biplex,* and large plant-like concretions - - -	8	0
Sandy beds more evenly bedded with *Pecten fibrosus* and *Serpula intestinalis* - - - - - -	5	0
Hard grey fossiliferous limestone with *Cerithium* - -	—	

Further up the valley *Ostrea bullata* is very plentiful in the shaly beds at the base of the series, immediately above the limestones.

Kirkby Moorside stands on this rock, which west of the town covers a large area of surface along the lower slope of the hill as far as Nawton. Between these places a deep section was exposed in making the railway cutting near Kirk Dale, but this is unfortunately now grassed over. The rock here consists in great part of a blue calcareous sandstone containing a large number of fossils principally Ammonites, but as far as we know they do not appear to have been preserved. Mr. Hudleston mentions the following from this neighbourhood: *Ammonites achilles*, d'Orb., *Am. decipiens*, Sow., *Am. Berryeri*, Leseur., *Gervillia angustata*, Röm., *Ostrea bullata*, Sow.

Between Nawton and Helmsley, from the beds being uplifted along an east and west line of fault, the Upper Calcareous Grit is much denuded, and occurs as a number of detached outliers, on most of which the rock is of no great thickness. At the latter place there is a good section of the rock just outside the town in the road going to Rievaulx; it here contains a band of large doggers or nodules similar to the ball beds of the Lower Calcareous Grit.

At Helmsley, where the beds turn round to the south, the outcrop of the Upper Calcareous Grit more or less follows the line of the York road to Oswaldkirk. On this bank the rock has a considerable thickness and the dip becoming more northerly it covers nearly the whole slope of this hill, passing regularly below the Kimeridge Clay of the vale along its northern foot.

From Oswaldkirk the outcrop extends eastward to the railway cutting at Nunnington Station, where is exposed one of the finest sections in this part of the Oolites to be found anywhere in the whole of Yorkshire. The rock is here very massive and blue-centred, and exhibits a similar tendency to run into lines of balls or doggers as at Helmsley. From this cutting Messrs. Blake and Hudleston mention the following fossils: "*Belemnites* (phragmacones of *B. abbreviatus* or of *B. nitidus*), *Ammonites*, sp. (cf. *Thurmanni*, Cont.), a very involute form, *A. biplex* (small interior whorls), *A. alternans*, Von Buch (*A. serratus*, Sow.), *Pecten midas*, d'Orb., *Modiola cancellata*, Röm. This last shell is not unlike the *Modiola pulchra* of Phillips (figured as a Kelloway fossil, pl. V. fig. 26). In Yorkshire it is usually indicative of a high position in the Corallian series, being found in the Hildenley limestone."

From this point the outcrop follows the northern slope of the hill by Nunnington to the end of the promontory at Ness, where it finally sinks beneath the alluvium of the Vale.

South of this escarpment the character of the beds alters considerably, and in the Howardian Hills a very different class of rock occupies the position of the Upper Calcareous Grit. At the extreme western end of this line of hills we have an indication of a slight change in character in the quarry at Snape Hill, which

is more fully developed when we see these beds again near the eastern end of this range; but owing to the large fault which bounds these hills along their northern foot we have no means of knowing what takes place in the intervening ground.

In the quarry at Snape Hill, above the isolated outcrop of Coral Rag previously alluded to there is the following section :—

Section in Quarry at Snape Hill.

		Ft.	In.
Sandstone with *Am. trifidus. Bel. abbreviatus, Pecten lens,* and *Astarte ovata?*		10	0
Calcareous series with alternations of sandstone and shale		13	0
Shaly series with bands of semi-argillaceous limestone		13	0
Shaly beds hidden by talus	3 0 to	10	0
Coral Rag with *Thecosmilia annularis, Cidaris florigemma,* and *Ostrea gregaria.* Base not seen	4 6		
Total Upper Calcareous Grit about		46	0

Here we see that, although the upper part of the section consists of sandstones not unlike some of the beds on the north side of the Vale of Pickering, there comes in below a considerable thickness of calcareous and argillaceous strata which does not occur along the northern outcrop. These lower strata we shall see presently are more fully developed at the eastern end of the Howardian Hills between Hildenley and North Grimston.

In the quarry at Snape Hill there are nearly 50 feet of strata exposed, and this will be about the full thickness of the formation; for although the Kimeridge Clay does not come on for some little distance, the sandstones dip with the slope of the hill, and appear to pass directly under it. The beds therefore, although changed in character, maintain about the same thickness that they have in the extreme east as proved by the borings at Irton and Filey.

Between Snape Hill and Hildenley, a distance of over 15 miles, there is no outcrop of these beds. At the latter place a narrow strip of argillaceous sandy limestone is seen in the low bank immediately east of the garden at Hildenley Hall, where also it was proved in digging the foundations of the hothouses. It dips rapidly to the south and appears to pass regularly under the Kimeridge Clay, the basement beds of which are seen in the brickyard close by. The outcrop is here, however, very limited, and does not appear to extend over half a mile in length. It is probable that this is merely a small patch turned up beneath the Kimeridge Clay by a fault ranging between the gardens and the hall.

East of the Derwent these beds are much better exposed, and have been quarried for building-stone between Langton and North Grimston; at the latter place they are also burnt for lime. They make a good hydraulic cement, and for this reason the name "North Grimstone Cement-stone" has, in this district, been given to these beds. The formation is in the main composed of bands of argillaceous limestone with partings of calcareous shale in

regular layers, rendering it very similar to some of the Lias beds of the South of England; in fact, the lime which is obtained from these beds so closely resembles in chemical composition that from the latter, that it has erroneously been called "Blue Lias Lime." The lower portion of these beds is more shaly and of no commercial value, and forms wet rushy ground which may easily be mistaken for the Kimeridge Clay, if no sections can be obtained.

The harder and more useful portion of the Cement-stone is probably not more than from 30 to 40 feet thick, but if we include the shaly beds below, the thickness will be double this, or as much as 80 feet or more.

The fossils from these beds are difficult to extract, and consequently the determinations are rather doubtful. Messrs. Blake and Hudleston give the following list:—

Belemnites hastatus?
—— nitidus* (B. explanatus, *Phil.*)
Ammonites biplex-varicostatus.
—— sp. (cf. Am. alternans and Am. serratus).
Gryphæa subgibbosa.
Pecten vimineus.
Pinna, sp.
Avicula, sp.
Lucina aspera, common.
—— sp.
Thracia depressa.
Pholadomya, sp. (cf. concentrica).
Goniomya literata.

These beds, which have evidently been formed from the denudation of the Coral Rag, are most irregular in their outcrop; and, being unconformable both to the Coral Rag below and also to the Kimeridge Clay above, they occupy positions in which it is frequently most difficult either to make out the physical structure of the country, or to determine whether their boundaries are lines of fault or not. They first appear on the southern slope of Langton Wold, dipping at a high angle into the fault which forms the southern edge of this hill, and, striking in a direction about E. 10° S., are continued to North Grimston. At this place the strata are thrown up by a large east and west fault, so that the Cement-stone comes on again in the quarry at the side of the railway, about 300 yards east of the great limestone quarries, from which it dips rapidly to the south, and passes beneath the Kimeridge Clay of the opposite side of the valley. The upper beds are here harder and more sandy, and have been quarried at the side of the beck, from which stone Wharram Church is said to have been built.

West of this point the Cement-stone forms the low range of Haver Hills, and a small patch is also seen below Luddith's House, apparently surrounded by Kimeridge Clay on all sides. Its outcrop is here broken by several faults, in consequence of which the dip is reversed, and the rock forms a good escarpment facing the south as far as East Farm, and again at Langton, where it has been opened out in several quarries; it is also well seen in the Birdsall and Settrington road, and along the beck towards Langton. In this direction the beds rapidly become more shaly, so that,

* "This is rather thicker than the usual Kimmeridge form, and is intermediate between the regular *B. nitidus* and *B. abbreviatus.*"

although there is a good feature at the village, the country to the south is low and very clayey, and exhibits nothing but grey shale, which might easily be mistaken for some other formation.

East of Birdsall these beds appear again, and occupy the eastern end of that valley, where they form the curious tabular feature of Picksharp Wood. The unconformity of the beds here is most marked, and the manner in which this feature runs across the valley from side to side, forming as it were a dam abutting against the Kimeridge Clay on either side, is very striking.

A small patch on the north side of the fault at Rowmire Spring is the only other outcrop of this formation. The Kimeridge Clay reposes directly upon the Lower Calcareous Grit throughout the whole of the country south of Birdsall.

It is possible that this division represents, to a certain extent, a portion of the Sequanien, which forms an important member of the Corallian series in France and Switzerland. The similarity also between this formation and the Cement-stone of North Grimston is greater than appears to have been generally observed. Owing, however, to the very few fossils that have been found in the rock, we can only note—in the first case that it occupies the same horizon, namely, at the base of the true Kimeridgian series; secondly, that they are lithologically very similar, M. Thurmann's account of the strata at Mont Terrible, ("Calcaires compactes, à cassure conchöide, et très-peu de fossiles,") being an almost exact description of the Cement-stone at North Grimston; and lastly, that both rocks appear to have been formed in a similar manner, namely, by the destruction and redeposition of the Corallian limestones upon which they rest.

The following fossils are noted from the Upper Calcareous Grit and Cement-stone:—

Fossils of the Upper Calcareous Grit and Cement stone.

ANNELIDA.

Serpula intestinalis, *Phil.*
Serpula tetragona, *Sow.*

BRACHIOPODA.

Discina elevata, *Blake.*

LAMELLIBRANCHIATA.

Avicula ovalis, *Phil.*, var. obliqua, *Bl. & H.*
*—— sp.
Exogyra nana, *Sow.*
Gervillia angustata, *Röm.*
Gryphæa dilatata, var. bullata, *Sow.*
*—— subgibbosa, *Bl. & H.*
*Pecten articulatus, *Schlot.* (P. vimineus, *Sow.*).
—— demissus, *Phil.*
—— fibrosus, *Sow.*
—— lens, *Sow.*
—— midas, *d'Orb.*
Perna mytiloides, *Lam.*
*Pinna, sp.
*Astarte ovata?, *Smith.*
Cardium delibatum? *De Lor.*
*Goniomya literata, *Sow.*
*—— marginata?, *Ag.*
—— v-scripta, *Sow.*
*Lucina aspera, *Buvig.*
—— substriata, *Röm.*
Modiola cancellata, *Röm.*
Myacites, sp.
*Nucula, sp.
*Pholadomya concentrica?, *Röm.*
Pleuromya tellina, *Ag.*
—— Voltzii, *Ag.*
Protocardium, sp.
*Thracia depressa, *Sow.*
Trigonia clavellata, *Sow.*
—— Voltzii, *Ag.*

* These species occur in the Cement-stone of the Howardian Hills; a few of them also in the true Upper Calcareous Grit.

GASTEROPODA.

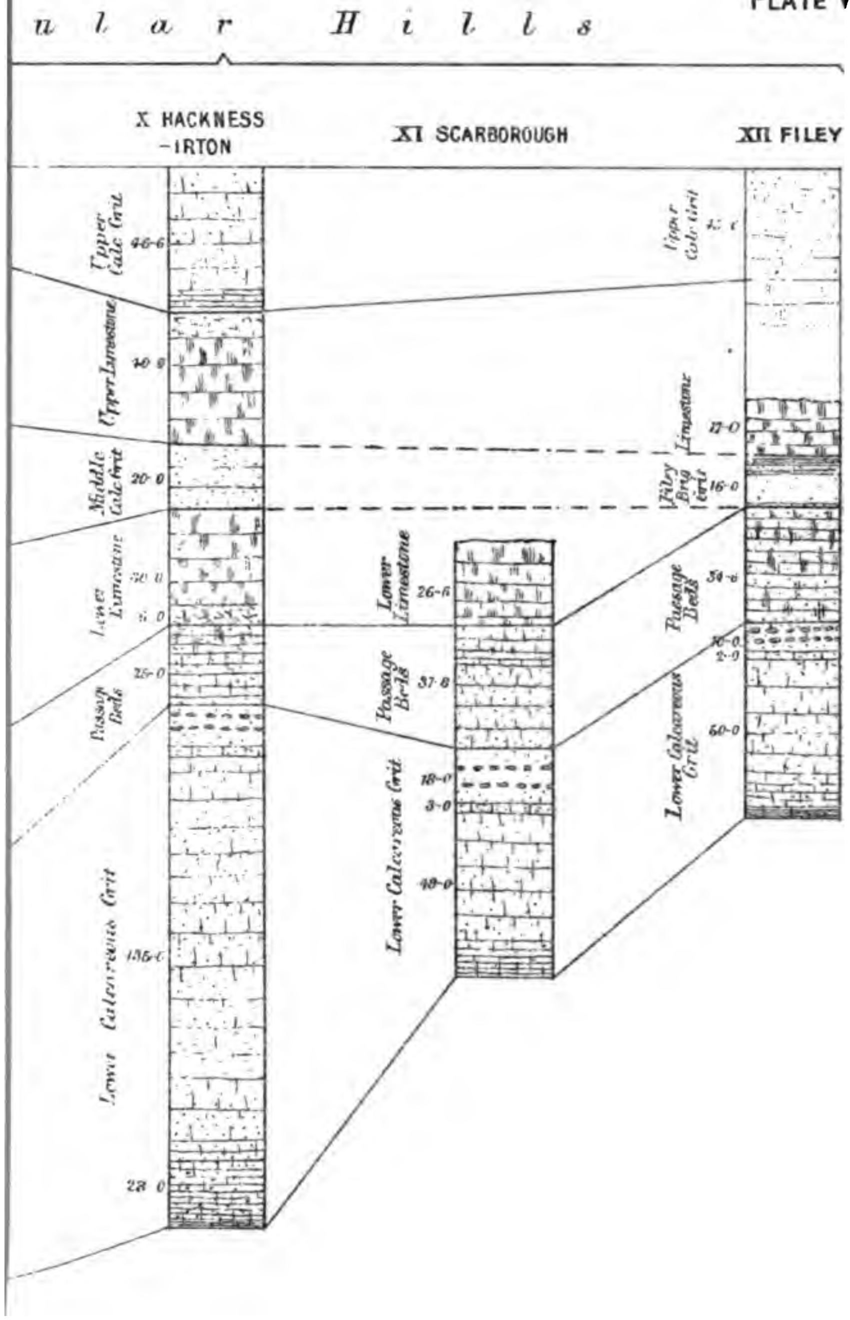
Patella rugosa, *Sow.*

CEPHALOPODA.

Ammonites achilles, *d'Orb.*
* —— alternans, *Von Buch.*
—— Berryeri, *Lesueur.*
* —— biplex, *Sow.*
—— decipiens, *Sow.*
—— Thurmanni ?, *Cont.*
Ammonites trifidus, *Sow.*
—— varicostatus, *Buckl.*
Belemnites abbreviatus, *Miller.*
* —— hastatus ?, *Montf.*
* —— nitidus, *Dollf.*
* —— semisulcatus, *Münst.*

* These species occur in the Cement-stone of the Howardian Hills; a few of them also in the true Upper Calcareous Grit.

PLATE VI.



Judd & Co. Lith. 6 3, Carter Lane, Doctors' Commons 2307.5.91

CHAPTER XV.
THE UPPER OOLITES.

KIMERIDGE CLAY.

Origin of the name.—The Kimeridge Clay was so named by Conybeare and Phillips in 1822 from the fine exposure of this clay in Kimeridge Bay on the South Coast; but in their "Outlines of Geology," the Yorkshire formation is not referred to, although Smith in his map of Yorkshire the year before had shown that the "Oaktree Clay," with which the Kimeridge formation was identified, was present in the Vale of Pickering. The name Kimeridge Clay was first adopted for the Yorkshire deposit by Prof. Sedgwick in 1826, who pointed out that the Speeton Clay was in great measure the equivalent of that formation; and, in his map of South Yorkshire, so represented the clays which crop out below the Chalk to the south of Newbald. This correlation was further confirmed by Prof. Phillips in 1829, who stated that while the upper part of the Speeton Clay had certain affinities to the Gault the lower part was certainly identical with the Kimeridge Clay.

Synonyms and Foreign Equivalents :—"Oaktree Clay," Smith, Strata identified by organized fossils, 1816, and Map of Yorkshire, 1821; "Argillo-calcareous formation of Kimmeridge and the Vale of Berks," Conybeare and Phillips, Outlines of Geology, p. 166, 1822; "The Upper Shale" (part), Young and Bird, Geological Survey of the Yorkshire Coast, p. 55, 1822; "Kimmeridge Clay," Sedgwick, On the Classification of the Strata which appear on the Yorkshire Coast, Ann. of Phil., ser. 2, vol. xi., p. 340, 1826.

"Marne argileuse havrienne," Brongniart, Tableau des Terrains, p. 410, 1829; "Marnes et calcaires du Banné" (part), Thurmann, Essai sur les soulèvemans, 1830; "Calcaire et marnes à Gryphées virgules," Thirria, Statistique de la Haute Saône, p, 145, 1833; "Facies littoral vaseaux à Exogyres et à Pterocères du terrain portlandien," Gressly, Obs. sur le Jura soleurois, 1838; "Weisser Jura ζ: Blaue petrefaktenarme Thone und Krebsscheeren kalkplatten (Solenhoferschiefer)," Quenstedt, Flözgebirge, p. 535, 1843; "Assise moyenne du groupe portlandien," Favre, Considérations géol. sur le mont Salève, 1843; "Calcaires et marnes a Ptérocères," Boyé, Géol. du Doubs, 1844; "Kimmeridgien," d'Orbigny, Terrain jurassique, p. 610, 1844; "Sequanien (part) et Kimmeridien," Marcou, Le Jura salinois, p. 104, 1846; "Étage supérieur du système oolithique" (part), Dufrenoy et Elie de Beaumont, Exp. de la Carte géol. de la France, Bd. II., p. 159, 1848; "Coraliien (part): Calcaire à *Ptérocéres;* Kimmeridien; Marnes à *Ostrea virgula*," Nerville, Exp. de la carte géol. du Dép. de la Côte-d'Or, 1853; "Zone der *Pterocera oceani* und subzone der *Astarte supracorallina*," Oppel, Juraformation, Tab. 64, 1856; "Pterocerasschichten, und Schichten des *Exogyra virgula*," Von Seebach, Der Hannoversche Jura, p. 56, 1864; "Die Kimmeridgeschichten," Brauns, Der obere Jura, p. 68, 1874; "Kimmeridien et Volgien inferieur" (part), Nikitin, Mem. du Comité Géol. Russ.;"* "Kimmeridgien et Portlandien" (part), Pavlow, Bull. Soc. Imp. Nat. Moscou, 1889.

With this formation we enter upon the closing scene of the extended period during which the grand series of Jurassic rocks was deposited in this part of England.

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* The term "Volgien" appears to have been first used in 1880. See the following works by S. Nikitin: Jura von Rybinsk, 1881, pp. 32–36; Cephalopoden von Kostroma, 1882, p. 70; and Bull. Com. Géol. Russ., 1884, pp. 58–60.

Although in the south of England the same general palæontological character of the rocks was maintained for some time longer, this was not the case in the northern area, unless we are to suppose that the evidence of such extension has been removed by denudation. This, we hope to point out in the sequel, was not the case; but, that, although somewhat similar physical conditions prevailed during the early part of the Cretaceous period, the change in life forms was most marked.

On the Continent the Kimeridge Clay has been separated into three zones; and, although there is much diversity of opinion as to their arrangement, the following is that usually adopted:—

Upper.—Zone of *Exogyra virgula*, Virgulien.
Middle.—Zone of *Pterocera Oceani*, Pterocerien.
Lower.—Zone of *Astarte supracorallina*, Astartien.

Oppel correlated the English formation with the zone of *Pterocera Oceani*, but placed some of the lower beds in the subzone of *Astarte supracorallina.**

Dr. Waagen, studying the exposure on the south coast of England, separated the formation into three horizons† :—

Upper.—Region of *Orbicula latissima* and *Acanthoteuthis speciosa.*
Middle.—Region of *Ammonites mutabilis* and *Exogyra virgula.*
Lower.—Region of *Ammonites alternans* and *Rhynchonella inconstans.*

Prof. Judd in describing the Speeton section adopted this classification, dividing the beds there exposed in the following manner‡ :—

Upper Kimeridge.	Dark laminated bituminous clay with hard slaty beds and occasional septaria; containing *Am. biplex* and other species of the group *Planulati*, *Discina latissima*, *Lingula ovalis*, &c.
Middle Kimeridge.	Light blue sandy clay with few septaria, darker and pyritic in the upper part; containing *Am. mutabilis*, *Am. triplicatus*, *Am. biplex*, &c.
Lower Kimeridge.	Dark coloured clays with septaria; containing *Am. alternans* and *Rhynchonella inconstans.*

In 1875 Prof. Blake reviewing the whole subject came to the conclusion that only two divisions were sufficiently distinct to be recognized in England:—the Upper Kimeridge which is fairly comparable to the Virgulien of foreign authors, and the Lower Kimeridge which includes the Middle and the greater part of the Lower of Dr. Waagen; while below this are a series of passage-beds which are only developed in the neighbourhood of the Coral Rag and contain as much of a Corallian as a Kimeridgian fauna.

The divisions recognized by Mr. Blake in other parts of England, together with the most abundant or characteristic fossils, are§ :—

* Juraformation, p. 742.

† Versuch einer allgemeinen Classification der Schichten des oberen Jura, 1865. Abstract in Quart. Journ. Geol. Soc., vol. xxi., part II., p. 14.

‡ Quart. Journ. Geol. Soc., vol. xxiv., p. 218.

§ *Ibid.* vol. xxxi., p. 196 *et seq.* Some of these species have not as yet been recorded from Yorkshire.

UPPER KIMERIDGE.

Ammonites biplex, *Sow.*
—— Thurmanni, *Cont.*
Discina latissima, *Sow.*
Exogyra virgula, *Defr.*
Cardium striatulum, *Sow.*
Lucina minuscula, *Blake.*

LOWER KIMERIDGE.

Ammonites mutabilis, *Sow.*
—— serratus, *Sow.*
Rostellaria mosensis, *Buv.*
Ostrea deltoidea, *Sow.*
Anatina minuta, *Blake.*

PASSAGE-BEDS.

Ostrea deltoidea, *Sow.*
Rhynchonella inconstans, *Sow.*
Serpula intestinalis, *Phil.*
And many Corallian forms.

The latter classification is that now generally accepted; therefore we may proceed to see how far it is possible, from the very imperfect evidence as yet obtained, to trace out these divisions in Yorkshire. Unfortunately the outcrop of the Kimeridge Clay in this district is nearly everywhere covered by thick deposits of Boulder Clay or Alluvium; so that it is only in a few obscure sections along Filey Bay, at a few places towards the western end of the Vale of Pickering, and along the western escarpment of the Wolds, which is much slipped and confused, that we get exposures of the beds.

The Upper Kimeridge consists of alternations of finely-laminated, dark, bituminous and lighter shale with hard brown bands.

These beds are first seen at the south end of Filey Bay in New Closes Cliff, and along the shore below as far as Butcher Haven.

They were exposed in 1883 and were measured by Mr. Lamplugh who has favoured me with the following section*:—

Section on the shore, opposite the ridge between Middle and New Closes Cliff.

	FT.	IN.
Coprolite bed	0	4
Black shaly clay with hardly any fossils; *B. Owenii*, var., *Ammonites* sp.	3	0
Solid black shaly clay with flattened fossils plentiful; *Am. biplex* ?, *B. Owenii* and vars. *Lucina minuscula*	5	0
Lighter blueish shaly clay	3	0
Darker ,, ,,	3	0
Brownish shaly clay, shows a disposition to harden into nodules, first brown band	1	0
Blackish shaly clay	1	0
Strong nodular band, brown nodules large and round	2	0
Dark shale with fossils; *Ammonites*, *Ostrea gibbosa*, *Discina latissima*, *Lingula ovalis*, etc.	9	0
Brownish shaly clay, nodules and hardened clay, second brown band	1	0
Dark shale; Saurian remains about the middle	8	0
Brownish shaly clay, third brown band	0	6
First dark and then lighter clayey shale softer than above	2	0
Shale greyish and very full of fossils so as to look speckled.		

* Since this was written Mr. Lamplugh has published this section in his account of the Subdivisions of the Speeton Clay. Quart. Journ. Geol. Soc., vol. xlv., p. 575.

The following fossils are recorded from the upper part of the Kimeridge Clay in Filey Bay.

Fossils of the Upper Kimeridge of Speeton.

Ichthyosaurus (vertebræ).	Avicula, sp.
Eurypoma (Palæoniscus) Egertoni.	Inoceramus, sp.
Ammonites biplex, and several species of the group *Planulati*.	Cardium striatulum.
Belemnites Owenii.	Lucina minuscula.
Alaria trifida ?	Discina latissima.
Ostrea gibbosa.	Lingula ovalis.
—— sp.	Pollicipes Hausmanni.

Inland there are no sections on this horizon till we get to Knapton, where Judd noticed a band of nodules which may represent a portion of the Portlandian beds; if this be so we probably have the highest part of the Kimeridge Clay in the bottom of these pits, although there is now no evidence as to what the clay is. Passing round to the west side of the Chalk Hills however we get a steep slope of Kimeridge Clay, which above Settrington is much slipped and broken up. The uppermost of the beds seen consists of black laminated shale with septaria, and contains *Discina latissima*, a clavellate *Trigonia* and other fossils, so that here probably we have a portion of the upper part of this formation; but it does not appear to extend much further to the south before it is concealed by the overlap of the Chalk, all the other exposures being in beds which must be referred to the Lower Kimeridge.

The Lower Kimeridge consists of blue clays and shales with septaria, which on the whole are much lighter in colour and not so finely laminated as the beds above. These beds are stated by Judd to be occasionally exposed in Filey Bay, extending for about a mile along the shore opposite Mile Haven; where he records the following fossils:—

Fossils of the Lower Kimeridge of Speeton.

Belemnites troslayanus.	Ammonites Berryeri ?
—— nitidus.	Exogyra virgula (var.).
Ammonites biplex.	—— nana.
—— alternans.	Pinna granulata.
—— mutabilis.	Modiola bipartita.
—— triplicatus.	Ceromya excentrica ?
—— marantianus ?	Thracia depressa.
—— yo ?	Rhynchonella inconstans.

There is however considerable doubt about these exposures of the so-called Middle and Lower Kimeridge of Filey Bay. Mr. Lamplugh, who from living in the neigbourhood has had frequent opportunities of visiting the coast at the most advantageous times during a number of years, states that he has never observed Kimeridge Clay fossils in the shale cropping out on the shore nearer Filey; but on the contrary has collected such undoubted Lias species as *Am. brevispina*, *Bel. clavatus*, *Bel. penicillatus*, *Gryphæa cymbium*, *Pinna folium*, *Plicatula spinosa*, &c. from these exposures.

These patches of Lias shale were also noted by Leckenby, who obtained from them *Am. communis, Am. bifrons* (*Walcotti*), &c.; and who thought they had been brought into this peculiar position by contortions or faulting of the strata.*

There is however we think but little doubt that they are portions of large drifted masses, similar to those which have been met with in North Yorkshire; and which have apparently been forced into this position by the great ice-sheet that occupied the plain of the North Sea during the Glacial period.

After leaving the coast the Kimeridge beds are hidden, with but few exceptions, till we get to the western end of the great Pickering valley. Quite the lowest beds however were passed through in the boring at Irton for the Scarborough Waterworks, where in a thickness of a little more than 40 feet *Belemnites nitidus* and *Ostrea deltoidea* were met with in great abundance.

More recently (1891) a boring has been made at Filey, which found the Kimeridge Clay to have a thickness of 75 ft. 6 in. at this point, but the beds with *Belemnites* and *Ostrea* were not recognized, possibly from the extremely comminuted state in which the material was brought up.

The Kimeridge Clay first rises above the bottom of the valley in the neighbourhood of Ebberston, where it forms a line of low hills at the foot of the northern range of Oolites, being cut off from them by a large east and west fault. The shales are seen in several small exposures, more particularly at Allerston and in the railway cutting at Thornton, but the sections are not of any extent, and have only yielded *Am. biplex* and a few undetermined fragments. The Kimeridge Clay has been met with in several deep borings about here, so that the beds seen may be assigned to somewhere near the middle of the formation.†

West of Pickering there are several exposures in the railway cuttings. These are now mostly grassed over, but numerous natural sections occur in this part of the country, especially in the isolated hills rising out of the flat, as at Risebrough and Marton,‡ where we have found *Am. cordatus*, and in the sides of the large streams which come down from the Oolites. Near Sinnington Manor House the junction of these clays with the Upper Calcareous Grit is seen, the shales being crowded with *Serpulæ* There is a good section also in the Hodge Beck near Bowforth where we obtained *Am. biplex, Avicula expansa,* and *Pecten subtextorius.* West of this the Kimeridge Clay was met with in the railway cuttings near Helmsley, but the sections do not tell us much, although they must all be near the base of the formation.

In the long tongue let down by the faults between Ampleforth and Gilling, the Kimeridge Clay is exposed at several places along

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* Geologist, 1859, p. 9. These exposures of Lias were first observed by Mr. Bean. See Leckenby, 23rd Rep. Scarborough Phil. Soc., p. 49. 1855.

† A boring was made at Ebberston in 1848; it was 140 yards deep; and coal 2 feet thick is said to have been found at 43 yards.—Thorp, Geol. Soc. Yorksh., 1855-6, p. 396.

‡ The Kimeridge Clay here contains some hard red sandy bands which have very much the aspect of burnt shale.

the sides of the low hills, which the formation makes in this valley. *Ammonites biplex* is here rather abundant, and a *Discina* occurs, but whether this indicates the presence of the higher division is doubtful; it is however probable that there is a good thickness of clay here, as a boring just south of Wass penetrated 400 feet of blue shales.*

FIG. 20.

Kimeridge Clay Lamellibranch.

Ostrea deltoidea, *Sow.* (after Sowerby) ½.

Passing now to the country south of Malton and the western escarpment of the Wolds, we have the basement beds of the Kimeridge Clay exposed in the brickyard at Hildenley, where Mr. Hudleston gives the following list of fossils† :—

Ammonites mutabilis.	Trigonia (clavellata, sp.).
Alaria mosensis.	Thracia depressa.
Ostrea deltoidea.	Myacites oblatus
Exogyra nana.	Pholadomya, sp.
Avicula ædilignensis.	

Along the steep slope of the Wold hills the Kimeridge Clay is frequently exposed from the slipping of the ground; and, with the exception of the higher beds at Settrington, as mentioned above, appears to belong exclusively to the lower division. From the shales along the lower part of the slopes here we have obtained *Ammonites biplex*, *Am. alternans*, *Am. cordatus*, *Exogyra subsinuata* ? ‡, *Ostrea flabelloides* ?. *Thracia depressa*, &c.

At North Grimston the basement beds are again exposed, the clays in the old brickyard here having yielded *Ostrea deltoidea* and

* Expl. of Quarter-Sheet 96 S.E. (Geol. Survey), p. 23.
† Quart. Journ. Geol. Soc., vol. xxxiii., p. 372.
‡ This is somewhat doubtful, but may indicate Cretaceous beds in this neighbourhood.

*Belemnites abbreviatus.** South of this the Kimeridge Clay skirts round the hills by Leavening and Acklam, till it passes beneath the Chalk and is finally lost by the overlap of that formation. In the neighbourhood of these villages *Ammonites cordatus, Belemnites nitidus, Ostrea deltoidea,* and *Serpula tetragona* have been obtained from the clay.

South of the overlap clays again appear from beneath the Chalk at Newbald: but from the absence of the whole of the sandstones and limestones intervening between the Kimeridge and Oxford Clays it is difficult to decide how much should be assigned to each formation. It is probable however that there are no clays of undoubted Kimeridge age till we get as far south as the Drewton valley, and even here there is not much evidence to rely upon. The Oxford and Kimeridge Clays in this neighbourhood formed a continuous deposit, consequently the fauna of the two formations become to a considerable extent mingled, and any division between them must be somewhat arbitrary. *Ostrea dilatata* which is usually considered a characteristic Oxfordian species is tolerably abundant, but as this fossil has been shown to pass up into the Kimeridge Clay in Lincolnshire it is not of any value.

At Elloughton the clay contains *Ostrea deltoidea, Belemnites nitidus* and *Ammonites serratus* (? *Am. alternans*), so that here if not before we reach the Kimeridge Clay coming in on the south side of the overlap, and continuing across the Humber into Lincolnshire.

The following list of fossils are those which have as yet been recorded in the Kimeridge Clay of Yorkshire:—

Fossils of the Kimeridge Clay.

ECHINODERMATA.

Pentacrinus, sp.

ANNELIDA.

Serpula tetragona, *Sow.*

CRUSTACEA.

Pollicipes Hausmanni, *K. & D.*

BRACHIOPODA.

Discina humphriesiana, *Sow.*
—— latissima, *Sow.*
Lingula ovalis, *Sow.*
Rhynchonella inconstans, *Sow.*
—— subvariabilis ?, *Dav.*
—— sp.

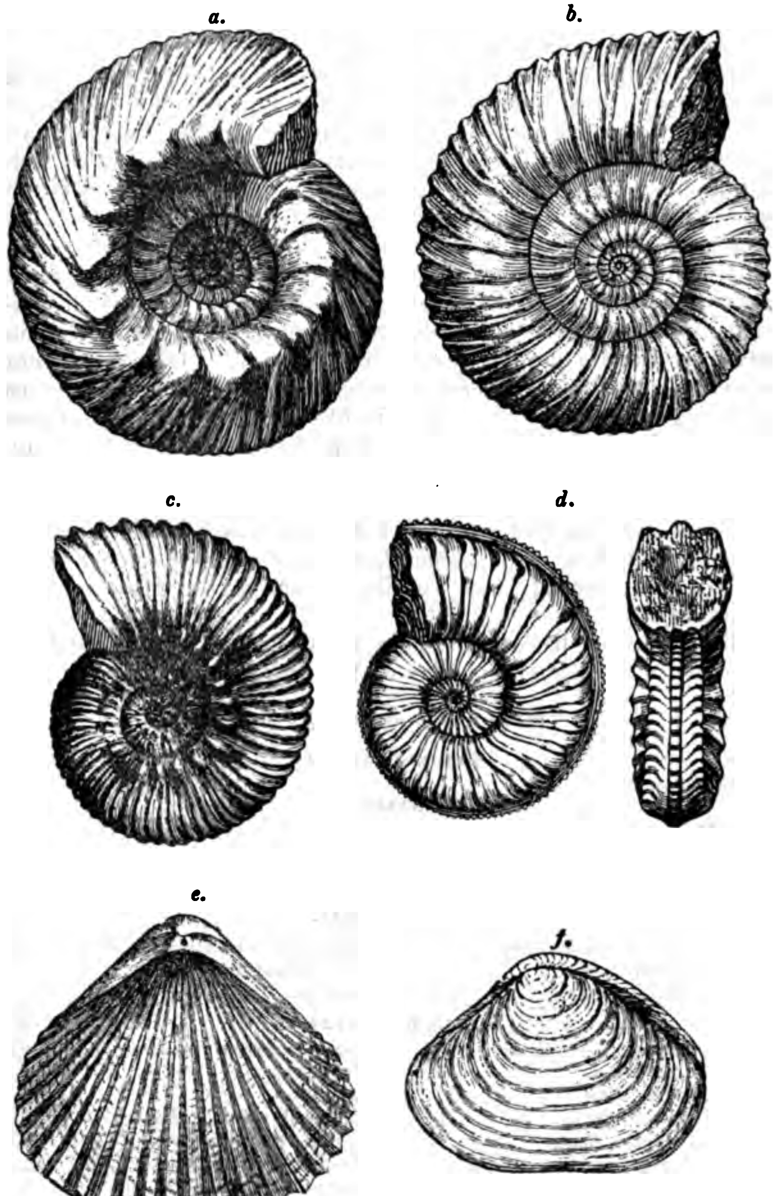
LAMELLIBRANCHIATA.

Avicula ædilignensis, *Blake.*
—— expansa, *Phil.*
Exogyra nana, *Sow.*
—— virgula, *Defr.*
Ostrea deltoidea, *Sow.*
—— gibbosa, *Lesueur.*
Pecten subtextorius, *Münst.*
Pinna granulata, *Sow.*
Astarte lineata, *Sow.*
Cardium striatulum, *Sow.*
Ceromya excentrica, *Ag.*
Cucullæa, sp.
Leda, sp.
Lucina minuscula, *Blake.*
—— portlandica, *Sow.*
Modiola bipartita, *Phil.* (non *Sow.*).
Myacites oblatus, *Sow.*
—— sp.
Thracia depressa, *Sow.*
Pholadomya decussata, *Phil.*

* Many ammonites are said to have been taken from here. Mr. Chadwick has obtained the following species from this neighbourhood:—*Am. eudoxus, Am. alternans, Am. acanthicus, Am. rotundus, Am. eumelus?, Am. mutabilis,* and *Ostrea deltoidea.*

FIG. 21.

Portlandian and Kimeridge Clay Fossils.



a. Ammonites gravesianus, *d'Orb.* (original) $\frac{1}{2}$; *b.* Ammonites biplex, *Sow.* (original) $\frac{2}{3}$; *c.* Ammonites eudoxus, *d'Orb.* (after d'Orbigny) $\frac{2}{3}$; *d.* Ammonites alternans, *von Buch.* (after von Buch) $\frac{2}{3}$; *e.* Rhynchonella inconstans, *Sow.* (after Davidson); *f.* Thracia depressa, *Sow.* (after Sowerby) $\frac{2}{3}$.

GASTEROPODA.

Alaria mosensis, *Buvig.*	Alaria trifida ?, *Phil.*

CEPHALOPODA.

Ammonites alternans, *Von Buch.*	Ammonites rotundus, *Sow.*
—— Berryeri, *Lesueur.*	—— trifidus, *Sow.*
—— biplex, *Sow.*	—— triplicatus, *Sow.*
—— cordatus, *Sow.*	—— yo ?, *d'Orb.*
—— eudoxus, *d'Orb.*	Ancyloceras sp.
—— eumelus ?, *d'Orb.*	Belemnites abbreviatus, *Miller.*
—— longispinus, *Sow.*	—— lateralis, *Phil.* (South Yorks.).
—— marantianus ?, *d'Orb.*	—— nitidus, *Dollf.*
—— mutabilis, *Sow.*	—— Owenii, *Pratt.*
—— plicomphalus, *Sow.*	—— troslayanus, *d'Orb*

PISCES.

Eurypoma Egertoni, *Egerton.*	Gyrodus Cuvieri, *Ag.*

REPTILIA.

Ichthyosaurus, sp.	Pliosaurus, sp.

PORTLANDIAN BEDS. ZONE OF BELEMNITES LATERALIS.

So early as 1859 Mr. Leckenby pointed out in Filey Bay the existence of a band of phosphatic nodules, and a thin series of clays containing a group of coronated ammonites highly characteristic of beds of Portlandian age.* These strata Mr. Judd further described in his account of the Speeton Clay in 1868, endorsing the views of Mr. Leckenby, although from the obscure and slipped condition of these clays he appears to have misunderstood their correct position.† According to the recent researches of Mr. G. W. Lamplugh there are two bands of phosphatic nodules at Speeton, and it is above the lower of these that the so-called Portlandian beds occur; so that the lower portion of the shales which were formerly supposed to be of Neocomian age are now placed in the Jurassic series.‡

It is however a matter of some doubt whether we are right in considering these shales as the equivalent of the Portlandian. It is evident that they do not represent this formation as it is generally understood, and it is very probable that there is no exact equivalent of them in western Europe. They appear on the other hand to have a great affinity with the Volga beds of Central Russia, which form a passage or represent an intermediate horizon between the Jurassic and Cretaceous periods.

M. Serge Nikitin in a lately published notice on the Speeton Clay considers it doubtful whether the coronated ammonites found on this horizon have been correctly identified, and is inclined to refer them to species which have been found in the Neocomian of Hils.§ It is very possible that the Port-

* Geologist, 1859, p. 9.

† Quart. Journ. Geol. Soc., vol. xxiv., p. 237.

‡ *Ibid.*, xlv., p. 583. Also Pavlow and Lamplugh. Argiles de Speeton et leurs équivalents. 8vo. *Moscow*, 1892. Prof. Blake classes these beds with the Neocomian, and considers that their reference to the Portlandian is founded on error. Proc. Geol. Assoc. 1891.

§ S. Nikitin. Quelques excursions in Europe occidentale, p. 39. 8vo. St. Petersburg. Also Bull. Soc. Géol. Belg., vol. iii., pp. 29–58. 1889.

landian beds of Speeton are the sole indication in western Europe of a great northern ocean which existed during the latter part of the Jurassic and the commencement of the Cretaceous epochs. As yet however our knowledge of these beds is scarcely sufficient to arrive at a definite conclusion on the subject, and therefore the short list of equivalents given below is made out on the supposition that they represent the so-called Portlandian of other places.

Synonyms and Foreign Equivalents:—"Speeton Clay" (part) of all the older authors; "Portlandian-beds," Judd, Quart. Journ. Geol. Soc., vol. xxiv., p. 237, 1868; "Calcaire miliare portlandien," Brongniart, Tableau des Terrains, p. 410, 1829; "Portlandien," d'Orbigny, Cours élémentaire, p. 561, 1849; "Calcaires et marnes à *Exogyres virgules*" (part), of many French Geologists; "Die schichten des *Ammonites gigas*," Brauns, Der oberer Jura, p. 119, 1874; "Lower Bolonian," Blake, Quart. Journ. Geol. Soc., vol. xxxvii., p. 585, 1881; "Le Volgien supérieur" (part), S. Nikitin, Les Vestiges de la Période Crétacée dans la Russie centrale, Mémoires du Comité Géologique, vol. v., No. 2, p. 201, 1888; "Zone of *Belemnites lateralis*," Lamplugh, Quart. Journ. Geol. Soc., vol. xlv., p. 585, 1889; "Zone à *Bel. lateralis et Olcostephanus stenomphalus*," A. Pavlow, Études sur les couches Jurassique et Crétacées de la Russie. Bull. Soc. Imp. Nat. Moscou, 1889.

These beds are exposed on the shore of Filey Bay opposite Black Cliff and Middle Cliff. North of this they run up into the cliff for a short space, but are again brought down by a roll of the strata, and crop out on the shore to the south of Hunmanby Gap for about three-quarters of a mile. It is only however after a continuance of heavy storms that the beds are really seen, and even then I believe the whole of them is never exposed at the same time; so that it is only by carrying on observations over a number of years that a complete section can be obtained. This has been done by Mr. Lamplugh from whom we quote the following account of the Portlandian beds of Speeton or Zone of *Belemnites lateralis* as he proposes to call them.*

Section at Speeton.

	Ft.	In.
"Compound nodular band": masses of pale limestone enclosing smaller brown argillaceous, pyritous and phosphatic nodules; and scattered black phosphatic stones. *Bel. lateralis*, *Am. noricus*, *Avicula inæquivalvis*, *Pecten lens*?, *P. cinctus*, etc. etc. Saurians	1	0
Dark gritty blue and brownish clays, with small nodules and phosphatic stones. *B. lateralis*, etc. etc., many fossils	4	0
Paler brown nodular band, indurated in places. *B. lateralis*, *Exogyra*, *Serpula vertebralis*, etc. etc.	0	6
Softer brown and paler striped clays; many fossils; *Exogyra*, &c.	3	0
Soft pale clay with brown nodules containing *Am. gravesianus*	0	6
Hard dark brownish pyritous clays; lower part few fossils; upper part many:—"Astarte-bed." *Astarte senecta*, *Bel. lateralis*, *Exogyra sinuata*, *Ammonites* sp., *Nucula* sp., *Serpula vertebralis*?, etc. etc.	10	0

* These pages were written before the publication of the account in the Quart. Journ. Geol. Soc., vol. xlv., p. 575; where Mr. Lamplugh has slightly altered the wording of the above section.

	Ft.	In.
Soft slate-coloured or brownish clay - - - - -	1	0
Blackish hard clay with some bright pyrites:—"Lingula-bed," *Lingula ovalis* ?, *Bel. lateralis* (weathered) - -	5	0
Hard pale blue clay, mottled and striped, but very pale and hard midway. *Bel. lateralis;* Crushed bivalves; small coprolite stones - - - - - - -	4	6
Brightly mottled seam - - - - - -	0	3
Striped bed, pale blue brown and mottled, greenish in places -	2	0
Dark blue clay with bright blue mottling - - -	0	4
Greenish black clay with hard Lias-like pyritous concretions -	0	8
Blackish clay; *Bel. lateralis*: fragments of shells; small pebbles ? - - - - - - - -	0	10
Hard black shale with worn irrecognizable Belemnites -	0	10
"Coprolite bed." *Bel. lateralis* ? or *sulcatus* ? *Ammonites* sp. *Lucina, Arca*, etc. (casts) - - - - - -	0	4

The "coprolite bed" at the base was formerly worked to some extent. The organic remains in it are in a bad state of preservation, but it appears to contain the bones of Saurians together with *Ammonites, Belemnites, Lucina portlandica* ?, and other fossils.

Inland these beds were supposed by Judd to crop out at Knapton, where a layer of phosphatic nodules 6 inches in thickness occurs in clays which he considered to be just below the Neocomian beds.* No fossils are mentioned from this place, and the pits being now entirely closed it is impossible to make out the relative position of the clays. Mr. Lamplugh, however, from an examination of the few fossils labelled Knapton in various museums, has come to the conclusion that the clays here belong rather to the upper part of the Neocomian than to the base of that formation.† Further to the south-west these clays disappear beneath the overlap of the Upper Cretaceous strata.

Between these places the outcrop is completely concealed by the Boulder Clay and Alluvial deposits of the Vale of Pickering, which along the foot of the Wolds have an average thickness of about 90 feet.

The following is the list of Portlandian fossils given by Judd and Lamplugh‡:—

Fossils of the Portlandian Beds.

Plesiosaurus, sp.
Other Saurian and Fish remains.
Ammonites biplex, *Sow.*
—— giganteus, *Sow.*
—— gigas, *Ziet.*
—— gravesianus, *d'Orb.*
—— irius, *d'Orb.*
—— rotundus, *Sow.*
Belemnites lateralis, *Phil.*
Avellana obsoleta, *Phil.*
Avicula inæquivalvis, *Sow.*
Exogyra sinuata, *Sow.*
Pecten lens, *Sow.* var. Morini, *De Lor.*
Arca, sp.
Astarte senecta, *Bean, MS.*
Nucula, sp.
Lucina portlandica, *Sow.*
Lithodomus, sp.
Lingula ovalis, *Sow.*
Rhynchonella inconstans, *Sow.*
Wood.

* Quart. Journ. Geol. Soc., vol. xxvi., p. 328.

† *Am. Deshayesii*, Leym. (*Am. knaptonensis*, Bean, MS.), *Am. noricus*, Schlot. *Terebratulina martiniana*, d'Orb., and *Pholodomya martini*, Forbes, are recorded from here. Naturalist, p. 337, 1890.

‡ In this list we have omitted some species from the "compound nodular band," as we consider its correlation with the Jurassic series very doubtful.

The Kimeridge and Portlandian beds of Yorkshire form a part of the great argillaceous series which succeeded the formation of the Corallian in north-west Europe. They represent the normal condition of deposits during this period, the calcareous and arenaceous beds of the South of England being merely local variations of limited extent, or as Mr. Blake* has called them "episodes" in the general uniformity. It would therefore appear that while marked physical changes took place in the south causing an upheaval of the ocean over an area of which the south coast may be roughly taken as the centre; in the north pelagic conditions still continued, or at any rate this district was beyond the influence of those causes which produced the sandy and calcareous beds of Portland.

* On Geological Episodes. Rep. Brit. Assoc. for 1879, Trans. of Sections, p. 385; Nature, vol. xx., p. 470.

CHAPTER XVI.

PHYSICAL HISTORY.

In this chapter we propose to consider how far we are able from the evidence before us to trace out the ancient physical history of this corner of England, and to show under what conditions the several series of rocks of which it is composed were built up.

But before entering upon this part of the subject it will be as well to consider what connexion the Jurassic rocks of Britain have with those of the Continent. In France and Germany these rocks occupy three distinct basins, which are partially separated from each other by mountainous ridges of older rocks. These have been named the Anglo-Parisian, the Pyrenean, and the Mediterranean basins respectively; but, as it is only with the former of these that the English beds have any connexion, we may dismiss the other two. The Anglo-Parisian basin is bounded on the south by the great central plateau of Auvergne, on the east by the Vosges mountains, and on the west by the palæozoic rocks of the old province of Brittany, while to the north it stretches across the Channel to unite with the beds of this age in England. In this country the strata present very different characters as we trace them from south to north. In the south in the majority of cases deep sea conditions prevailed, but as we get further north especially in Yorkshire, and again in Scotland we have evidence of much shallower water, and that we are approaching the limits of the formation. In these latter districts there is evidence that land must have been in the immediate neighbourhood, and in many cases the surface actually rose above the level of the sea during the deposition of the Jurassic rocks. How far these conditions prevailed we have no means of ascertaining, but it is probable that they extended over a very large area; for although in Scotland the evidence obtained is of a very scattered and fragmentary character, in Scania the southern province of Sweden, we have beds of the same age showing similar estuarine conditions.* Thus it appears that the Jurassic rocks of Yorkshire, which are those with which we are at present concerned, were as a whole laid down towards the northern extremity of the great Anglo-Parisian Basin; although there were intervals during which much deeper water prevailed, and the confines of the ocean must have been more distant. We will now proceed to see to what extent the character of the rocks themselves bears out this supposition.

* Mr. Godwin-Austen considered that the greater part of the North Sea was land during the Oolitic period. Quart. Journ. Geol. Soc., vol. ii., p. 46*, and map. This land however must have laid chiefly to the north of our latitude during the deposition of these estuarine strata.

In an inquiry of this sort there are several points to consider—the limits of the area in which similar deposits occur; the position of the land bounding this area; the conditions that prevailed during the period; the alterations of level that took place; the palæontological and petrological character of the rocks; the climate that produced these characters. With regard to the first of these points it has been shown by the writings of many English and Foreign geologists that the Jurassic rocks of Britain, Northern France, and Western Germany constitute one life province in which the same forms appear, but modified by the conditions that surrounded them. We are thus able to compare our own area with that of the Continent, and to point out what relation the English Jurassic rocks bear to those deposited in the same marine province. In the present case however we are only concerned with a small portion of this area, but one which is unique in its character and which is also of considerable importance from its forming a link between the marine beds of the south and the estuarine strata of the northern limits of this great province.

The Jurassic rocks of Yorkshire lie in a basin-shaped hollow, forming a compact little district which is almost entirely isolated from beds of the same age throughout the rest of England.

Around the three sides on which the lowest beds of the Jurassic rocks are exposed, north, west, and south, they are found to rest directly and conformably on the Trias; in fact the change from one to the other is so gradual that it is difficult to decide where the line should be drawn between them. This latter formation has been proved from numerous boreholes to be of considerable thickness, so that there is not much doubt that it underlies the whole of this eastern part of Yorkshire, and forms the foundation of the strata with which we are more immediately concerned. It is now pretty generally acknowledged that the Upper Trias, at least of England, was laid down in large lakes or inland seas, in which the deposits of rock salt and gypsum it contains were precipitated by the evaporation of the water. Towards the close of this period these inland seas became dry or nearly so, either from filling up with sediment or from elevation of the ground; as is proved by the thin beds of ripple-marked sandstone in the upper part of the Keuper Marl, which are covered with pseudomorphous crystals of rock salt, and which could only have been formed on the margin of these lakes. Following this a gradual subsidence of the ground took place, probably chiefly on the eastern side, which let in a shallow sheet of salt water from the open sea. In this shallow water the Rhætic Beds were deposited, containing a stunted fauna that had migrated from a deeper Rhætic sea, but here found the conditions not so well suited to their development. If we examine the Rhætic Beds of the Continent we find that those of northern Europe were deposited under very different conditions from those of Lombardy, and that while the latter contain a well-developed marine fauna, the former present much fewer species, and these are mostly small and distorted.

In our own area, a continuation of the depression continuing, the water became deeper and more open; and, gradually expanding into a true Liassic ocean, the conditions became favourable for the life of that period. That these changes were very gradual is proved by the complete passage that exists from the Trias to the Rhætic and from the Rhætic to the Lias. Throughout the whole of the Keuper Marl there is a continual repetition of the same sort of beds, from red into green marl, and from green marl into greenish grey sandstone, but these changes become much more frequent towards the upper part till they pass into the sandstones and limestones with black shales which constitute the Rhætic Beds. The white shales, and the small band of white compact limestone, which we have taken as the top of the Rhætic Beds, have the appearance of having been tranquilly deposited in an inland sea, and probably exemplify the last of those alternations that took place before the more permanent subsidence of the Liassic period.

With the commencement of this period very different conditions prevailed; the stunted fauna disappeared and were replaced by one more fully developed; there is also greater uniformity in mineral character, and very shortly Cephalopoda began to appear, showing the presence of an open sea or ocean. As we advance further in the period these conditions become more marked, both by the abundance of the Ammonites and Belemnites, which characterize the beds, and also by the great thickness of argillaceous strata. What was the character of the succession of events, which produced the zones of life into which the Lias has been divided, is a point upon which we do not care to enter. Particular groups of Ammonites came in in great abundance throughout certain beds, the Arietites in the Lower Lias, the Amalthei in the Middle Lias, and the Falciferi in the Upper Lias, but what were the conditions which caused these peculiar restrictions is a question that has not as yet been properly solved; it is evident however that great periods of time must have elapsed while these changes of form took place in the process of evolution.*

In which direction the land lay that bounded this open sea is a question we are better able to answer. The Lower Lias along the northern margin about Redcar contains numerous oyster beds, and gives some evidence of having been deposited in comparatively shallow water; and we shall see presently that the higher strata towards the north-west also point to the fact that the old shore of the Liassic ocean lay in that direction. There is no evidence in Yorkshire of an actual shore-line, as is the case in South Wales, along the flanks of the Mendips, and again in the Hebrides in the extreme north-west of our islands. The great uniformity of these argillaceous strata points to the fact of their having been deposited under tranquil conditions somewhat removed from any disturbing influence such as an old shore line. The material of which they are

* The gradual changes which took place in the Cephalopoda of the Lias have been ably worked out by Prof. Phillips and Dr. Wright in the Monographs of the Palæontographical Society, and by Mr. Blake in the Yorkshire Lias, p. 327.

composed was evidently derived from the old palæozoic land to the north-west, probably occupying the position of the present outcrop of these beds along the Pennine chain and part of Scotland, but possibly also extending beyond the limits of these islands and stretching across the northern portion of the North Sea, connecting them with Scandinavia.

This would furnish the argillaceous matter from which the shales were derived, while the lime and iron would be precipitated and form the doggers so characteristic of this part of the Lias, pyrites being induced by contact with animal matter. While speaking of the formation of doggers it may be as well to say a word on the peculiar structure known as "cone in cone" which is so often associated with them. This structure has been attributed to crystallization, to the action of pressure upon concretions in the course of formation, and to the chemical decomposition of sediment. As far as the first of these propositions is concerned we may say that the Yorkshire specimens do not exhibit any structure that can be referred to crystallization. More likely they were caused by pressure which has been induced by the contraction of the interior whilst the exterior of these nodules was in a semi-plastic condition. It is, however, a structure which is as yet far from understood, and which requires further investigation by various methods of research.*

Between the upper beds of the Lower Lias and the lower portion of the Middle Lias there is no marked lithological or palæontological distinction; the argillaceous strata of the one pass gradually into the sandstone of the other, and it is evident that the shallow water conditions of the Middle Lias succeeded gradually to the deeper water of the previous period. Whether this was brought about by the elevation of the land, or by the gradual filling up of the Liassic ocean is immaterial. The evidence afforded by the change from argillaceous shales into sandy shales, and from sandy shales into sandstones, the latter of which are often ripple-marked, and also by the organic remains, consisting of frequent bands of Oysters together with a considerable variety of Asteriadæ and Ophiuridæ, is such that there can be no doubt that littoral conditions prevailed during the formation of the sandstones of the Middle Lias. During the latter part of the period a slight subsidence again occurred, the sandstones being succeeded by more argillaceous strata interstratified with numerous bands of ferruginous matter constituting the Ironstone Series. With regard to these latter several theories have been put forward to account for their origin, and different views are held as to the manner in which the ironstone was originally deposited. At present the iron contained in these seams principally occurs as bicarbonate, but it is evident that it could not have been deposited in that form, as

* Yates, Trans. Geol. Soc. v. 375; Dickinson, Quart. Journ. Geol. Soc. ii. 131; Sorby, Brit. Assoc., 1859; Marsh, Proc. American Assoc. Science, 1867; Jukes and Geikie, Manual of Geology, 1872, p. 312; Young, Geol. Mag., 1885, p. 283; Newberry, *Ibid.*, p. 559; Young, Min. Mag. vi. 13; Geol. Mag., 1886, p. 139; *Ibid.*, 1892, pp. 138, 480; Trans. Geol. Soc. Glasgow, viii. 1, 1886; Gresley, Geol. Mag., 1887, p. 17; *Ibid.*, 1892, p. 432; Harker, *Ibid.*, p. 240; Garwood, *Ibid.*, p. 334.

the action of the sea water would have converted it into peroxide. Prof. Sorby considered that these seams were originally laid down partly in the form of limestone interstratified with clays containing a large amount of oxide of iron and organic matter, which, acting upon one another, gave rise to the formation of bicarbonate of iron.* A curious fact in connexion with this subsequent alteration is that it does not appear to have affected all the shells contained in the rock in an equal manner; thus in the thin laminated shells, such as the Ammonites, the Dimyaria, and the Gasteropoda, the carbonate of lime has been replaced by iron, while the thicker shells such as the Belemnites, the Monomyaria, and the Echinodermata have retained their original carbonate of lime. The reason for this appears to be that many shells such as Ammonites are composed of aragonite, while others such as Belemnites are composed of calcite. The latter of these minerals, it has been shown by Messrs. Cornish and Kendall,† is much more stable than the latter; and that while shells composed of aragonite are rapidly acted upon by a solution of carbonic acid, those formed of calcite are not so easily affected. Mr. Hudleston also inclines to this view of substitution, and points out how the iron has been derived from the superincumbent rocks by a process of leaching or gradual dissolving of the iron disseminated through these beds, which has been rendered soluble from the reductive action induced by the carbon contained so abundantly in the remains of vegetation scattered throughout these rocks. The iron thus rendered soluble as a protoxide is readily removed and accumulates along certain horizons; where, from further oxidation, it becomes insoluble and fixed to these places.‡

In many cases the oolitic grains are fractured, and the general appearance of the rock is such as would indicate a disturbed condition of the water in which it was deposited. This is more particularly the case towards the north-west, where we have the principal evidence of the vicinity of an old shore-line; to the east deeper water prevailed, giving rise to the splitting up of the ironstone seams, and the deposition of a larger amount of argillaceous matter; while to the south the extreme thinness of these beds shows that little or no sediment was being laid down. Nowhere in Yorkshire is there actual evidence of a shore-line, but from the general appearance of the beds it is probable that land lay not far to the north-west of what is now Eston Moor, which formed the head of a gulf or somewhat

* Sorby, Proc. Yorkshire Geol. Soc., vol. iii., p. 457, 18 7; Quart. Journ. Geol. Soc., vol. xxxv., Proc. p. 84, 1879. In an appendix to this paper (published privately) Dr. Sorby gives microscopic sections of several of the Yorkshire rocks, including specimens from the Coralline Oolite, Calcareous Grit, Cornbrash, Grey Limestone and Kellaways Rock. This subject was originally investigated by Gustav Rose, Abhandl. K. Akad. 1858 (Phys) p. 63; and Zeitschr. Deutsch. Geol. Gesell. X., p. 191, 1858. It has also been ably discussed by Prof. Judd who, in explaining the origin of the Northamptonshire ironstones, has traced out the similar series of changes which have taken place in the formation of that deposit. Mem. of the Geol. Survey. Geol. of Rutland, p. 130.

† V. Cornish and P. F. Kendall. On the Mineralogical Constitution of Calcareous Organisms. Geol. Mag., dec. iii., vol. v., p. 66, 1888.

‡ W. H. Hudleston. On the Geological History of Iron Ores. Proc. Geol. Assoc., vol. xi., pp. 104–144, 1889.

sheltered sea in which the shales, ironstone seams, and nodular bands were tranquilly deposited. In South Yorkshire the whole of the Middle Lias becomes very much thinner, and in fact almost dies out; it is therefore evident that this district must have been, by some means or other, beyond the influence of deposition, either by its forming dry land at the period or from its being too remote from the source of sediment. The former of these suppositions appears the most probable, if we may regard the occurrence of oolitic ironstone at Sancton as indicating the proximity of land. This land may have existed as a promontory* separating the Yorkshire basin from the Liassic sea of South Yorkshire, and have been formed by a slight uprising of the strata along an east and west line parallel with the present direction of the Howardian Hills; which foreshadowed the greater disturbance that in later times shattered the Oolitic rocks of this neighbourhood, and separated the seas in which the Lower Cretaceous beds of Speeton and those to the south of Malton were respectively deposited.

The basement beds of the Upper Lias (the *annulatus*-shales) are very similar both lithologically and palæontologically to those of the Ironstone Series; and were probably deposited under somewhat similar physical conditions. From the clear passage of one set of beds into the other, it is evident that the gradual lowering of the bed of the sea continued, till in course of time the far deeper water and more open sea, which obtained during the remainder of the Upper Liassic period, appeared.

The strata deposited during this latter period, from their uniform character and the absence of any sandy material, show that the shore must have been at some distance from this area, but whether it was entirely removed from the influence of land is doubtful. The presence of jet in the lower part of these shales is in favour of land not being very far off; for whether the origin of jet be waterlogged coniferous wood, as stated by some, or due to the segregation of bitumen in the intervals of the shales as believed by others, it is evident from the highly bituminous character of the Jet shales, that vegetation existed in some form or other at this period. Again the Saurian remains, which are so abundant in the Upper Lias afford some indication that these strata were formed in the neighbourhood of land. For although the Ichthyosaurus was undoubtedly marine, and from the great size and strength of the eyes seems to have been an inhabitant of very deep water, the appearance of the Plesiosaurus and the character of its respiratory organs were such that it could only have lived in very shallow water, and probably frequented the neighbouring shore, as may be surmised from the resemblance of its extremities to those of the turtle. The gigantic Teleosaurus

* There is no evidence that North and South Yorkshire were entirely separated at this time; but, as all the divisions of the Lias present somewhat different characters in the two areas respectively, it is probable that they were connected by open sea further east.

also, which shows considerable analogy with the modern crocodile, was probably a fluviatile reptile, and if so is not likely to have been found far from land.

The difference in character between the Jet Shales and the Alum Shales may be accounted for by the more rapid deposition of the latter; while in the same manner that the presence of vegetable matter gave rise to bitumen in the one, the presence of animal matter in the other gave rise to bisulphide of iron from which the sulphate of alumina was obtained for the manufacture of alum. The presence of a greater amount of salts of sulphur in the Alum Shale of Yorkshire, than in the Lias of other parts, may be accounted for from the sea having been to a certain extent landlocked; so that the water became concentrated by its more rapid evaporation, and sulphates were deposited.

From the foregoing remarks we may observe, that although the Lias was a marine deposit, still no part of the formation appears to have been formed in very deep water or far removed from land; and that, while some of the beds show that they were laid down under distinctly littoral conditions, the majority were deposited in very tranquil water from which the carbonates of lime and iron were quietly precipitated to form the numerous bands of nodules or doggers, which are so remarkable a feature of the Yorkshire Lias. For this reason we are inclined to think that the Yorkshire beds must have been formed in a somewhat landlocked area, which had its shore-line to the north-west, and possibly was enclosed also to the north and south, but was open towards the east, in which direction it had free communication with the waters of the Liassic ocean. The South Yorkshire deposits were formed beyond this district, and constitute the northern limit of a much more extended area, in which the waters were far more calcareous than in this Yorkshire gulf.

Towards the close of the Liassic period the bed of the sea was elevated, or the water became shallower from the gradual accumulation of material. That these changes took place much more rapidly in the west than in the east is shown by the different nature of the beds in the two areas. On the coast the Blea Wyke Beds exhibit a considerable thickness of sandy shales with *Serpulæ, Lingulæ*, &c., showing shallow-water conditions and forming a gradual passage from the Lias below; but in the west the upper part of the Lias has been subjected to considerable local denudation, proving that it was elevated, and became dry land a long time prior to that in the extreme east. A curious fact in connection with the Blea Wyke Beds is that they appear to be cut off sharply to the north by the Peak fault, beyond which they have not been found. Mr. Hudleston has suggested that this may have been caused by the fault being partly formed before the deposition of the Dogger, so that this unique section of the Blea Wyke Beds has been preserved on the coast, while they have been swept off or were not deposited elsewhere.* This idea

* Proc. Geol. Assoc., vol. iii., p. 304.

seems to be further favoured by the fact that, although the Blea Wyke Beds are evidently a littoral deposit, there is no evidence of an actual shore-line previous to the formation of the Dogger, and therefore these beds must have extended some way further west than where we now find them.

With the commencement of the Oolites a great change took place, the whole area was elevated, but apparently in an unequal degree; a portion became dry land and was exposed to great local denudation, cutting out a considerable thickness of the Lias beds already deposited, as in the neighbourhood of Bilsdale and elsewhere; another portion, and in fact by far the larger part of the area, was more or less between tide-marks, or oscillated between dry land and very shallow water; while a third or remaining portion which lay principally to the west consisted of somewhat deeper water in which the calcareous beds of the Dogger along the western escarpment were laid down. In this latter area these calcareous beds are excessively irregular, occurring at isolated intervals, between which they have either thinned out or are of a totally different character, and probably show the presence of a series of narrow inlets connected with a larger sea to the west. The larger deposits of ironstone may have also been laid down in this manner, as they appear to have consisted mainly of carbonate but whether they have been formed by replacement from the limestone, as has been suggested in the case of the Middle Lias ironstone, is doubtful. The magnetic iron ore of Rosedale, which occurs in two long troughs or lenticular patches 70 feet thick, is considered to have been converted into magnetite by the agency of heat, but why this particular deposit was affected and no other is not very clear. Robert Hunt considered that this ore especially resembled the hydrated magnetic oxide, which can be obtained as a precipitate from an aqueous solution, and that it showed indications of having been a carbonate of the protoxide not unlike that of Cleveland, but exposed to influences which have changed it into magnetite.*

The semi-marine conditions, which ushered in this period, were comparatively not of very long duration; the seas retreated from a large portion of the area, although there were still probably long inlets or straits running up here and there into the land, the margins of which in course of time became covered with a dense vegetation. Although the Lower Oolites consist of several alternations of marine, estuarine, and freshwater strata, they really constitute but one series when looked upon from a physical point of view. Local changes were continually taking place in the physical geography of the period, frequent oscillations of level occurred, now on one side, now on the other; so that, although estuarine conditions always prevailed in some part, they were often interrupted by incursions from the sea.

We will now proceed to consider in what direction these several movements took place. The thickness of the estuarine beds

* Quart. Journ. Sci., 1868, p. 33.

increases towards the north; while along the western escarpment these beds are far more arenaceous than they are on the coast. It is therefore apparent that the material from which they were formed must have been derived from a north-west direction. This supposition is further confirmed by the observations of Mr. Sorby, who, in studying the structure of the sandstone beds of the Yorkshire Oolites, noticed that the general direction of the currents, which produced the drift-bedding and ripplemarks, was from the N.N.W.* How far off this land lay is matter of conjecture, but it is evident that the river which could have brought down so large a mass of material must have been far greater than any at present existing in these islands: there is however no reason for supposing that the Lower Oolites of Scotland and elsewhere were deposited in the same estuary as the Yorkshire beds, although they may have been contemporaneous. What was the general character of the land at this time has been well described by Prof. Ramsay in his account of the physical geography of the period.† "In the south of what is now England the seas were broad and comparatively shallow, during all the time of the deposition of the Lower Oolites, and the islands round which these seas flowed (including Wales) were comparatively small. But further north we come to a fragment of a much larger land, formed of Palæozoic rocks, that in those days formed a mountainous country, extending from the hills of Derbyshire far away to the northern extremity of Scotland, and how much further entire, or broken into islands, no man yet knows. In spite of disturbances of upheaval of later date than these Oolitic times, it may also very well have been that this old land was much higher than the highest Highland mountains of the present day, seeing the vast amount of waste and degredation they have undergone since that ancient time, and we may be sure that it was surrounded by seas of this lower Mesozoic epoch, for fragments of the Oolitic strata still surround the island. This was the larger land, from which the rivers flowed that deposited the freshwater sands described above. On the low banks of these rivers grew many a plant now represented merely by indistinct impressions—

'Their meaning lost,
Save what remains on stone, or fragments vast'—

in which the relics of species of *Araucaria*, *Cycas*, *Zamia*, *Screw Pine*, and numerous other forms, together with the gigantic *Equisetums* which grew in the still waters on their borders, while Marsupial mammals on the shores and Trigoniæ and Terebratulæ in the seas, help us to realise that the physical characteristics of the time in some degree resemble that of Australia in our own day, a circumstance first noticed by Professor Owen."

During this period the north-east of Yorkshire formed part, either of the estuary of some large river, or possibly of a series of channels or straits between the neighbouring islands. Whatever

* Proc. Yorksh. Phil. Soc, 1850, p. 111.

† Physical Geology and Geography of Great Britain, 5th Ed, p. 196.

was the exact condition of the physical geography at the time, it is evident that large masses of sand and sandy mud were brought into the area; that these were frequently denuded and rearranged by powerful currents which were constantly changing their courses, and that while one part was upraised above the level of the water and gave rise to a luxuriant vegetation, another was exposed to inroads from the sea bringing a marine fauna, but which was frequently stunted from the unfavourable condition of its surroundings. After the deposition of the Dogger the whole area appears to have been cut off from the influence of marine conditions for some time; vast accumulation of sand took place, the greater part of which was deposited in the north; a dense vegetation composed principally of Equisetaceæ, Cycadaceæ, and a few ferns grew on the surface of the land, which had been recently raised above the level of the water, or cut off from it by alterations in the prevailing channels. This vegetation produced the thin coal seams that are dispersed throughout the Lower and Middle Estuarine Series, and which vary in thickness from about three feet to mere streaks of coaly matter. That these coal seams are composed of plants which actually grew upon the surfaces where we now find them, and are not the result of drifted vegetation as has been suggested, is proved by an underclay representing the old soil being found beneath them full of their decayed roots.

While these beds were being deposited in the north, a much more extensive sea existed to the south of this area. Here throughout a great part of the period more open water prevailed, free from much sediment, in which the purer limestones of the Lincolnshire Oolite were laid down.* The lowest part of this formation extends northwards into Yorkshire, becoming separated from the main mass of the rock a little north of the Humber, and continuing as a thin bed of dense argillaceous limestone (the Hydraulic limestone of the Howardian Hills) nearly as far as Thirsk on the western escarpment, north and east of which its place is taken by the Eller Beck Bed. This latter, from its arenaceous character and stunted fauna, was evidently deposited in very shallow water, probably in lagoons or inlets unsuited to a vigorous marine life.

Returning again to the south, we find the upper part of the Lincolnshire Oolite also extending north in a series of more or less sandy oolites, which gradually become thinner, till they die out altogether in the neighbourhood of Thirsk. On the coast also the same thing occurs. To the south of Scarborough the Millepore bed, the equivalent probably of purer limestones which may have existed to the south, is a semi-calcareous rock full of the fragments of a shallow-water fauna, and is evidently a littoral deposit. Further north this rock becomes very much thinner, and a little beyond Cloughton loses its calcareous character, becoming very similar to some parts of the Eller Beck Bed, after which it

* Prof. Judd estimates that the Lincolnshire Oolite was formed in an area of depression having a diameter of about 90 miles. Geol. of Rutland, p. 148.

dies out altogether. Thus it appears that in Yorkshire we have the northern limit of the old sea basin, in which the Lower Oolite was deposited; and that, while thick beds of oolitic limestone were being laid down in the counties of Northampton, Rutland, and Lincolnshire, a varying shore-line existed in this district, accompanied by an alternate advance and retreat of the marine water.

During the early part of this period marine or brackish water extended over nearly the whole of this part of Yorkshire for a short time, causing a thin bed of limestone to be deposited in the southern part of the area; while along its northern limit the marine fauna only existed under very unfavourable conditions, and were soon overwhelmed by the great influx of sand and mud, in which we now find their casts. This was followed by a rapid advance of sand and mud from the north, which drove back the sea nearly to the southern limit of the county, and filling up the old depression converted much of it for a second time into dry land. Again the sea advanced; but this time, although its northern limit did not extend beyond a line running from Northallerton to Whitby, the water was clearer and better suited to the development of such forms as Echinodermata and Corals. At this time a shore-line probably existed in the east,* causing currents in which the broken up shell fragments were redeposited; while further north we find a thin layer of the same shells, which, although they were not exposed to the violent action of the waves, found their surroundings not so favourable; a fact which seems to indicate the existence of some sheltered lagoon in this direction. To the south of Scarborough brackish-water conditions also followed in some places, the calcareo-arenaceous Millepore bed of Gristhorpe being succeeded by clays and sandstones, with a generally dwarfed fauna and a few Crustacea.

After a while the northern limit of the sea again retreated and estuarine conditions prevailed, which in course of time filled up the depression, and for a third time the land advanced southwards. Probably none of this land was much elevated above the level of the sea, but consisted of a flat muddy shore or series of lagoons among which winding streams or currents were constantly shifting their courses, cutting new channels and filling up the old ones. On the sides of the streams, and in the swamps around the lagoons a luxuriant vegetation sprang up, of which we now find the remains in the plant beds and coal seams which form so remarkable a feature of the Yorkshire Oolites. On studying these plants we perceive that the majority of the species are ferns, which certainly had a most extraordinary development, although it is probable that more species have been described than really exist.† Many species of these ferns may be common to both the

* Mr. Godwin-Austen considered that the Oolites of Yorkshire and Lincolnshire were dependent on land which lay to the east, but this is the only case in which we have evidence of a shore-line in this direction; nearly all the other divisions of the Jurassic rocks point to the influence of the land having been on the opposite side. Quart. Journ. Geol. Soc., vol. xii., p. 64.

† Carruthers. Proc. Geol. Assoc., vol. iv., p. 330.

Lower and Middle division of the Estuarine Series, at least this is what we should expect from the presence of land having existed more or less continuously in the northern part of the area during the period; but from the confusion of the two series by the early collectors, and also from very few species having as yet been obtained from the northern moorlands where the two series come together, this is a point we cannot determine. Cycads and Coniferæ are also fairly abundant, but usually marked by different genera, thus *Otozamites* are common in the lower, while *Pterophyllum* are most frequent in the higher beds. Marsh-loving plants such as the *Equisetites* are common, but purely marine forms are rare, showing that although the sea was probably in the neighbourhood, it but seldom obtained access to the vast swamps in the interior. The fact of these plants being found erect, and rooted in the soil in which they grew, affords striking evidence of the gradual accumulation of sediment, and of the tranquil condition under which it was deposited.

At the close of this period the land was again depressed, and the waters of the sea were admitted in which the Grey Limestone Series was deposited. These beds attain their greatest thickness about Peak, where their general appearance gives indications of having been formed in deeper water than elsewhere.

About Eston Moor, on the opposite side of the outcrop, their excessively coarse character shows that the land was not far from that point. It is therefore probable that a shore-line existed somewhere to the west, and not far from the present north-west outcrop; so that arenaceous beds were formed in the west, while calcareo-argillaceous strata were deposited in the east. This sea had apparently no connexion with the south, for these beds thin out a little to the south of Malton, and to the south of Gristhorpe on either side of their outcrop; it is probable therefore that the southern limit of the sea was near the former of these places, in the neighbourhood of which the sandy strata of the Howardian district were deposited. The waters of this sea were far less calcareous and more muddy than those ot the previous Millepore bed, and consequently we find no corals and but few Echinoidea, while the Asteriadæ and Cephalopoda are more plentiful.*

The Estuarine period which succeeded, although somewhat similar to those that went before, does not appear to have been so favourable to the development of plant life. Only a few species have as yet been found in these beds, and there are no coal seams anywhere throughout the whole area. The strata are excessively false-bedded, and there is frequent evidence of strong currents having cut out large portions of the strata in one place, and re-deposited them in another. In the cliffs to the south of Scarborough and one or two other places, the sandstones contain the

* The presence of *Cetiosaurus* at White Nab affords but little evidence of the nature of its surroundings, so little being known of the habits of this saurian. It is at present doubtful whether it was a marine, estuarine, or terrestrial animal; although the structure of the bones, as far as they have as yet been discovered, is in favour of the latter.

casts of a few shells, which show that limited areas of fresh or possibly brackish water were occasionally formed. On the whole therefore these beds appear to have been laid down under less tranquil conditions than those of the Middle Estuarine Series; and it is probable that there was less land surface at this time, although the sea itself was kept out by the powerful currents which brought down and deposited the irregular mass of sandstone and shale which constitute this series. At intervals however a portion of the land must have been above the action of these currents, during which a few freshwater bivalves lived in the ponds and swampy hollows between the different streams, but were soon covered up and buried by the accumulation of sand and mud brought down by the encroaching waters of the estuary.

After a while a depression again took place, bringing in the sea on the north-east side of the area, from which the thin but excessively fossiliferous limestone known as the Cornbrash was deposited. This sea does not appear to have extended over the west and south of the district, as no trace of the rock has been found there, nor have we found any break in the sequence of the beds at this horizon. This at first sight appears rather curious as the Cornbrash is the most constant throughout England of all the Oolitic rocks, extending from one end of its outcrop to the other apparently without much alteration. It may, however, be accounted for on the supposition that dry land or estuarine conditions continued in the western part of the intermediate area until the commencement of the Oxfordian period; while at the same time a continuous sea-line existed further east by which the fauna of the Yorkshire rock was connected with that of the South of England.

That the two areas were connected is proved by the identity of many of the fossils, but that the local conditions were different is shown by slight variations in many of the species.

It is therefore evident that the Yorkshire area was connected with that of the South, not along the present line of outcrop, but probably further east, by some communication which existed during a portion only of the Great Oolite period, and that the northern part of Yorkshire formed an inlet of this far larger sea. The plentiful assemblage of fossils in the Cornbrash proves that the conditions were favourable for a rapid development of marine life for a short time, the great abundance of oysters and other littoral shells showing that the water was comparatively shallow; while the profusion of brachiopoda, which had been almost absent since the commencement of the Oolites, point to some change in the character of the sea which rendered it suitable to this branch of the mollusca.

We now enter upon the third great period during which the Jurassic rocks were formed; this, which for convenience has been called the Middle Oolite, is separable into the two main divisions of Oxfordian and Corallian. These, which in Yorkshire consist mainly of sandstone and limestone, constitute an episode in the great argillaceous formations (Oxford and Kimeridge Clays) which

took place further south; so that, while deep water prevailed uninterruptedly throughout the central part of England, frequent variations in a comparatively shallow sea occurred in the northern county.

At the commencement of this epoch conditions were pretty much the same throughout a large part of England; so that in the earliest formation, the Kellaways Rock, we have similar characters presented, although far more feebly in the southern area. Very shortly however a change occurred causing a great thickness of clay to be accumulated throughout the larger part of England, while but little really argillaceous strata were formed in Yorkshire.

In this district the close of the Lower Oolite period was marked by a further alteration of level, which brought in an incursion of muddy water that rapidly destroyed the prolific fauna of the Cornbrash, although a few forms still lingered on.

By this means was formed the thin bed of shale which, from the continuance of these few species, has been classed with the Cornbrash, but which really marks the commencement of the great physical changes which introduced the Oxfordian period. This subsidence still continuing communication was gradually opened up with a sea swarming with new species of Cephalopoda in which the Kellaways Rock was deposited, and which from the abundance of new forms of Ammonites had no parallel since the days of the Lias. In tracing the Kellaways Rock along the coast, Mr. Hudleston has noticed that different groups of Ammonites occur in strata which are apparently contemporaneous; and that whatever may be the cause of this it is a noteworthy fact that the deposition of the Kellaways Rock in Yorkshire occupied a sufficiently long period as to include the Ammonites of two horizons which are usually separated in other regions. This fauna attains its maximum development in the upper part of the rock; the rest of the formation is comparatively barren or contains forms which more nearly approach the estuarine character of the Lower Oolite.

The rapid attenuation of these beds in a southerly direction is most remarkable, from a thickness of nearly 80 feet at Scarborough they decrease along the coast to about 10 feet in a little over four miles; further inland the variation is equally striking, the sandy beds, which may be classed with this rock, having a thickness of over 100 feet in Newton Dale, while due south in the eastern part of the Howardian Hills they are represented by only a few feet of sand. This rapid but uniform attenuation of the Kellaways Rock in a southerly direction affords incontestable proof that the sandy sediment of which it is composed must have been derived from the north; also the fact of the nature of the material from which it was formed being of a similar character to that of the Lower Oolites is additional evidence that the source of these sands was from the same locality. It is therefore probable that the land bounding this sea was not very far from the present most northerly outcrop of the rock which laid down this great

thickness of sand in Yorkshire, while throughout the rest of England merely a few feet of calcareous-arenaceous strata were being deposited. These in the south of Yorkshire evince shallow water conditions, and, containing abundance of the peculiar round form of *Gryphæa dilatata—Gryphæa bilobata*, which is also very plentiful beneath Roulston Scar, afford further proof that the Oxfordian sea did not extend much beyond these outcrops in a westerly direction.

After the formation of the Kellaways Rock, the subsidence which had commenced with the early part of the period was greatly increased and deeper water prevailed over a part at least of the area in question. The sea was invaded by muddy currents, which rapidly killed off the teeming life of the previous period, and accumulating a great thickness of strata over a large area, formed the Oxford Clay. This did not however take place uniformly over the whole of the Yorkshire basin, but principally towards the south-east. In this direction the Oxford Clay attains its greatest thickness, but thins out altogether in the south-west; while between the two the lower beds are composed of several alternations of sandstone and shale showing that oscillations of level or variable currents occurred in the intermediate area. It is therefore apparent that the Oxfordian sea attained its greatest depth during this portion of the epoch; that this was greatest towards the south-east; and that, while shoals and sandbanks existed in the northern part of the district, the extreme west was for a time at least either above the influence of deposition, or too near the shore to allow of the formation of shales. The very gradual passage there usually is from the Oxford Clay into the overlying Lower Calcareous Sandstone, and from the Sandstone into the Limestone, shows that the change in physical conditions between them also took place very slowly. It is probable that from a gradual filling up of the sea more sandy beds came again to be deposited, and from some means, but how is not very clear, the conditions became more favourable for the propagation of a marine fauna which throughout the Lower Calcareous Grit, Passage Beds, and Lower Limestone became tolerably abundant.

The Oxfordian beds of Yorkshire are, from the general character of the fauna, separable into two divisions—a Lower Oxfordian, which includes the Kellaways Rock and the lowest beds of the Oxford Clay, and an Upper Oxfordian, which includes the Lower Calcareous Grit, Passage Beds, and Lower Limestone: between the two the main mass of the Oxford Clay from the almost entire absence of fossils in it, forms a well-marked break, the fauna of the one dying out in quite the lowest beds of the formation, while that of the latter does not appear in any force till well up in the sandstones of the Lower Calcareous Grit. With the setting in of the Upper Oxfordian fauna the water became clearer and more free from mud: this change occurred sooner in the west than in the east, and over portions of the western area succeeded immediately to the similar conditions of the Callovian or early

Oxfordian sea, no argillaceous deposits, as we have noticed, having intervened between the sandy beds of the Kellaways Rock and the Calcareous Grit.

This latter, as we have seen in the general description of the strata, is a somewhat peculiar rock containing considerable lithologically variety, and evidently formed under many different physical conditions. It was originally much more calcareous than we now find it; the porous nature of the rock, and its dense blue-hearted character, when met with at any distance from the surface, is sufficient proof that much lime has been dissolved out. Much of this has been redeposited in the veins of calc spar which traverse the rock, and which are so numerous on the west side of the Castle Hill at Scarborough and elsewhere. One peculiarity of the rock is the large amount of silica it contains, both disseminated through the rock and collected into nodules. This we may suppose was derived from siliceous organisms, sponges, diatomaceæ, &c.* which inhabited the sea, together with the calcareous mollusca which are so largely represented; that these organisms were dissolved by water percolating through the rock and redeposited in the form of chert; and that this subsequently became segregated along certain lines producing the bands of cherty rock and lines of nodules, which are so characteristic of these beds. In the upper part of the rock these nodules are very marked, and form a conspicuous line of huge balls or doggers, many of which are several feet in diameter: these balls exhibit a curious reticulate structure, which has suggested the idea that they may be the fossil remains of sponges; but whether this is the case or not has never yet been clearly made out. The siliceous matter however appears to be entirely withdrawn from the surrounding rock, and to have collected along the most fossiliferous beds, leaving a loose porous sand in which they are now embedded, and which easily crumbles away on exposure to the air. Another peculiarity of the Calcareous Grit is the speckled appearance of some of the beds, which shows that the rock had a tendency to become oolitic, and that the physical conditions under which it was formed were approaching those that produced the true oolitic limestone. This latter, as has so often been pointed out, has a very close resemblance to beds which are now being formed in the neighbourhood of coral islands; and there can be but little doubt that the Yorkshire limestones were formed under very similar conditions.† Every trace of these islands has now been removed, except the

* Dr. Hinde has drawn attention to the important part played by the globate spicules of sponges in the formation of the Calcareous Grit. Quart. Journ. Geol. Soc., vol. xlvi., p. 54, 1890.

† See Nelson, on the Bermudas and Bahamas, Trans. Geol. Soc., 2 Ser., vol. v., p. 103, and Q. J. G. S., ix., p. 200; Darwin, "The Structure and Distribution of Coral Islands," 1842, Ed. 3, 1890; Jukes, "Narrative of the Voyage of H.M.S. *Fly*," 1847; Dana, "Corals and Coral Islands," pp. 152, 194, 1872, Ed. 3, 1890; Wyville Thompson, Voyage of the Challenger, i., pp. 306 315; Murray, The Structure and Origin of Coral Reefs and Islands. Proc. Roy. Soc. Edinb., vol. x., pp. 505–518; and Nature, vol. xxii., pp. 351–355, 1880. A very useful summary on this subject is "Die Theorieen über die Entstehung der Koralleninseln und Korallenriffe und ihre Bedeutung für geophysische Fragen." Von Dr. R. Lagenbeck. 8vo. Leipsic, 1890.

small fragment of a reef which we have remaining around Hackness; but it is possible that a large part of this material was derived from a great barrier or fringing reef extending along the flank of the old palæozoic land to the west, which land we have every reason for believing existed during the whole of the period.

That these various conditions of the sea-bed existed simultaneously is proved by the very diverse character of the equivalent strata in different parts of the area; thus in the east the Calcareous Grit gradually succeeded the Oxford Clay, and was equally gradually followed by the calcareous waters, which produced the Passage Beds and Lower Limestone; in the west there was little or no argillaceous sediment to form the Oxford Clay, but a clear sea existed which deposited the oolitic limestones and sandstones that we find resting directly upon the Kellaways Rock. In this portion of the district the limestones and sandstones are so dovetailed together, that it is evident they were formed of constantly varying sediment, sometimes sand, sometimes lime; and that frequent irruptions of sand took place in a sea that was at times tolerably clear and suited to the formation of coral banks. These varying conditions of the physical geography of the period are well described by Mr. Hudleston in the following passage:—"It is impossible not to believe, as regards the Lower Calcareous Grit, that some calcareous beds, with more or less of oolitic structure, were being deposited in one area whilst more gritty beds were being deposited in another simultaneously; indeed we may feel sure, as regards the entire formation, that one thing was going on at one place, and another thing at another. Oolitic granules would, therefore, be conveyed by currents like so much sand; and the further they were carried the smaller they would become, till many of them would be no bigger than pins' heads. Multitudes of such bodies would be sealed up with the grits in the banks that were in process of formation, together with other calcareous matter. In the course of geological time many changes, due to substitution and removal, have greatly modified such porous beds as these. Solutions of silica and calcic carbonate, under the influence of various natural re-agents, have been perpetually traversing these beds, which seem also to have been freely percolated by acidulous waters. That which may have once been the minutest of oolitic granules, transported far away from the reef to which it owed its origin, is soon dissolved, and its place is empty, or filled with a more abiding substance, and thus the pinholes and specks of calc grit may have in part arisen."* Mr. Hudleston goes on to show that, although it may be objected that there were no reefs in the Oxfordian Sea at the period when the lower portion of the Calcareous Grit was being deposited, from which oolitic granules could be derived, still fringing reefs may have existed nearer the original shore, but of which all traces have been removed.

* Proc. Geol. Assoc., vol. iv., p. 385.

Besides these smaller oolitic granules, which have evidently been formed by the deposition of lime round a solid particle, there are at certain horizons, notably near the base of the Upper Limestone, pisolitic beds in which the individual grains are as large as peas. This class of rock, it has lately been suggested by Mr. Wethered, is formed by the tubes of minute Foraminifera of the genus *Girvanella*, and that consequently its origin is organic.* We are, however, not aware that the Yorkshire beds have as yet been subjected to examination, so that we merely mention the fact as suggestive of future research.

The inosculation of the limestones and grits in the extreme west, and the existence of a thick bed of limestone at the very base of the Calcareous Grit near Kilburn, is in favour of fringing reefs having formerly existed not far to the west. Also, from the dying out of the Limestone in the south and towards the north, as well as towards the east, it is probable that its present outcrop corresponds very nearly with its original area of deposition; which did not extend much to the north of Hackness, to the east of Filey, or to the south of Malton. The beds are thickest to the west of Pickering, while further west still they become split up with intercalated beds of sandstone, and so interwoven with the Calcareous Grit that it is plain that the Lower Calcareous Grit and Lower Limestone are but varying conditions of the same formation. These changes also took place more abruptly in the west than in the east. Throughout the whole of the eastern part of the outcrop, between the Hodge Beck and the Coast there is a gradual passage from the Calcareous Grit to the Limestone; but west of this the change is much sharper and no intermediate beds can be traced. It would appear therefore that during this period the western part of the area was nearer the source of sediment than the eastern; so that, while calcareous beds tranquilly succeeded arenaceous deposits in the east, in the west the sea bed was subject to frequent irruptions of sand for short periods, which covered up the limestone, but being quickly checked allowed fresh masses of calcareous matter to be deposited.

These limestones are succeeded by an important bed of sandstone, the Middle Calcareous Grit, during the deposition of which much change took place in the life of the period. This change is first noticeable, as pointed out by Mr. Hudleston, in the top bed of the limestone, the fossils in which appear to foreshadow the fauna of the Upper Limestone. It would appear that, by the changes in progress at this time, some barrier was removed, which let in the waters of an ocean charged with a different fauna. These were at first mostly destroyed by the great irruption of sand which produced the Middle Calcareous Grit and which is in the lower part nearly destitute of fossils; but after a while they again found conditions favourable for their development. The Middle Calcareous Grit, like most of the other arenaceous forma-

* Geol. Mag., dec. iii., vol. vi., p. 196, 1889; Quart. Journ. Geol. Soc., vol. xlvi., p. 270, 1890.

tions, is thickest at the western end of its outcrop, but thins away both to the south and east, showing that the source of sediment was still in the former direction; while to the south, although the fauna inhabiting the sea underwent considerable change, still calcareous beds were continuously laid down; as seems to be the case at Malton, where there is little if any physical break between the limestones, notwithstanding the great difference in the palæontological character of the two.

During the deposition of the Upper Limestone and Coral Rag this calcareous sea gradually regained its sway over the whole of the Yorkshire basin, but whether everywhere at the same time is doubtful. From the previous account of these beds it will have been seen that they are more or less separated by denudation into several districts—Ayton, Pickering, Hambleton, and the Howardian Hills, which to a certain extent have different characters, and some of which appear to have been formed in different basins.* How far this is the case we have no means of knowing, the presence of a few species in one bay or inlet that are not found in another is no proof that the two were not connected, but rather that one situation was more favourable to certain individuals than another; the geological record is at present so imperfect that negative evidence is of little value in drawing deductions of this kind. During the early part of this period the physical conditions were very similar to those that obtained during the formation of the Lower Limestone; except that the sea was less liable to incursions of sand, and altogether appears to have been more tranquil, and further removed from land than during the former. These limestones, however, are not on the whole nearly so oolitic as the lower beds, and consist very largely of hard dense pasty rock, in which the oolitic grains and fossils are cemented together into a compact mass. The oolitic grains are much fewer and larger than in the Lower Limestone, and altogether the rock shows that its origin was somewhat different. Mr. Hudleston has suggested that this class of rock may have been formed by physical events which took place in the following manner:—"The coral is being perpetually ground down to the finest powder, which is held suspended in the sea like ordinary sediment; but as it falls towards the bottom, it encounters an acid stratum of water, due to the quantity of carbonic acid generated by the decomposition of organic matter and the respiration of animals. This slightly attacks the calcareous sediment and forms the usual soluble bicarbonate, which is again precipitated as calcic carbonate amongst the interspaces of the slowly settling mud, thus cementing the whole into a mass of most compact rock, and gluing up all the shells."†

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* Mr. Hudleston has suggested that the whole of the Upper Limestones, Oolite and Rag, of the district between Seamer and Brompton, may be older than much of the Coralline Oolite of Pickering. Proc. Geol. Assoc., vol. v., p. 420.

† *Ibid.*, p. 431.

Besides the oolitic and "pasty" condition of the limestone there are other varieties of the rock, such as the "black posts," and other beds which have not received local names; these indicate that the physical conditions of the sea bed underwent many changes, and also that much diversity prevailed locally throughout the district. For, although this part of the country must have been submerged during the greater part of the time that the Coralline Oolite was being formed, still certain portions may have been above the level of the water, or at least the sea was so shallow that the strata previously deposited were exposed to denudation. This was the case at Pickering in the early part of the period; where, in the basement or passage beds of the limestone, we find the valves of the *Trigoniæ* always disunited and much worn by attrition, accompanied by a growth of coral, itself a further proof of the littoral character of the sea bed. In the quarries at Malton, Mr. Hudleston has pointed out that "we have three different classes of rock, with a marked change of character in each, showing an alteration in the nature of the sediment, which not unlikely means a cessation of deposit within the area, or even a partial submarine denudation before each fresh set of beds was deposited."* Here therefore, but at a somewhat later date, there were also interruptions in the steady accumulation of deposits; and we see that, although the formation of the Coralline Oolite took place continuously over a large part of the district, still local variations occurred which affected only small portions of the area.

After awhile the great banks of coral, which had probably been growing in the immediate neighbourhood, gradually encroached, as the water from the destruction of these older reefs became sufficiently shallow to enable the reef-building Polyps to thrive, upon those districts where we now find their remains. These coral reefs, as indicated by the present outcrop of the Coral Rag, were scattered and fragmentary, and show that their original outline must also have been very irregular. A good instance of one of these reefs exists at Ayton, which Dr. Wright has described in the following words:—"One quarry, near Ayton, which may be considered as a type of the others, consisted of masses of crystalline coralline limestone, the beds having an irregular undulating appearance. The corals appear to have grown in areas of depression of the coralline sea; the rock consists of large masses of highly crystalline limestone, forming nodulated eminences and concave curves, in beds of from twelve to eighteen inches in thickness, having a stratum of yellowish clay filling up the hollows, and forming a horizontal line again to the stratification; then follows another stratum of crystalline limestone, which assumes the same nodulated condition as the one below it, the surface of the coral masses, where exposed, showing that the whole is almost entirely composed of a small-celled *Astræa*,

* Quart. Journ. Geol. Soc., vol. xxxiii., p. 366. See also *ante*, Fig. 17, p. 341.

Thamnastræa concinna, Goldf. (*Th. micraston*, Phillips), in some altered condition; the reef is exposed to about ten feet in section, and rests on another, forming the floor of the quarry, and which descends many feet deeper. The corals are bored by *Gastrochænæ*, and numerous shells are seen imbedded in the coral mass, which had nestled in the crannies of the reef."*

In the western part of the district the branching forms of coral such as *Thecosmilia annularis, Rhabdophyllia Phillipsii, Cladophyllia Conybeari*, are much more common, and form the greater part of the Coral Rag about Kirkby Moorside and in the Howardian Hills, on either side of the Vale of Pickering; so that, although these reefs were probably more or less contemporaneous, the conditions were slightly different which favoured the development of other genera of Actinozoa. Many of the beds in the latter area, as at Hildenley, Sike Gate, and North Grimston, seem to be due to the denudation of Coral rather than to its actual growth. In point of fact the Coral Rag presents a great number of slightly different phases, due to the different positions in which the beds were deposited relative to the then existing land; and are the result of a slight difference in physical condition affecting the life of the period, rather than of changes brought about by lapse of time. Thus there is a general absence of the larger and stronger species of mollusca in the Coral Rag; but it is particularly rich in the tests and spines of Echinodermata, the delicately marked Gasteropoda and other coral haunting shells, which lived in the sheltered recesses of these old coral reefs.

We will now consider the physical conditions under which these coral reefs were formed. Reef-building corals require water of a temperature of about 68° to thrive; their growth is checked by fresh or muddy water; and they cannot live at a greater depth than 15 or 20 fathoms. To satisfy the conditions suitable to this state of things implies a climate in Britain analogous to the tropical and semitropical regions of the present day. The waters of this Jurassic sea were studded with coral reefs and atolls which extended over the greater part of western Europe, but their growth was here and there checked, at one time by the presence of muddy sediment, at another by the too great depth of the water; so that, although Yorkshire must have been near the northern limit of this sea, it was more favourably situated than many places further south. This however was the last time that the climate of Great Britain and the condition of its seas were suitable for the production of coral reefs on a large scale.†

Whether, in this district, the growth of coral extended much beyond the present outcrop of the Coral Rag is a question we are unable to answer. As we have said before, there is some reason for supposing that the Limestone below was formed from coral

* Dr. Wright, "On Coral Reefs Present and Past." Proc. Cotteswold Club, vol. iv., p. 61.

† The only indications of coral reefs in Britain at a later date are that formed during the Tertiary Period, and the feeble semblance of one in the Portland Oolite. See Duncan, Quart. Journ. Geol. Soc., vol. xxvi., p. 60.

reefs bordering the old Palæozoic land to the west, it is therefore not probable that these later reefs extended any further if so far; but rather that they were formed continuously along the margin of this new made land, and that as part was destroyed, new growth took place further east; the present Coral Rag being the last remaining fragment that was left when the land sunk beneath the influence of denudation. When this took place we have the formation of the Upper Calcareous Grit, in which the physical conditions that produced the Lower and Middle Calcareous Grit are repeated, but with a different fauna. This rock, like most sandstone beds, is of no great extent, only occurring in any force along the northern side of the Pickering Valley, its place on the southern side of this valley throughout the Howardian Hills being apparently occupied by the North Grimston Cement-stone. This latter is a dense argillaceous limestone such as might be formed in moderately deep tranquil water along a coast composed of limestone rocks; but too far removed to be influenced by littoral action, and therefore beyond the zone in which either oolite or sandstone would be deposited.

How these rocks so very different lithologically from each other came to be deposited contemporaneously, appears to have happened something in the following manner. A depression of the coralline sea was accompanied by a great influx of sand and mud from the north brought down by some large river; this at first only conveyed the muddy sediment which forms the sandy shales at the base of the rock; but, as the volume of the water increased, sands were borne along and deposited over the area where we now find the Calcareous Grit, while the lighter muddy material was carried further south into deeper water rendered very calcareous by neighbouring coral islands, where the two mingled together and formed the calcareous shales and argillaceous limestones of the North Grimston Cement-stone. That this was the origin of these beds seems to be further supported by the fact that in the extreme west at Snape Hill near Coxwold, which is intermediate between the localities where the two classes of rock are developed, there is a gradual passage up into sandstone from argillaceous calcareous beds very similar to the Cement-stone but more argillaceous. It is therefore probable that, while sandstone containing a tolerable abundance of cephalopoda was being deposited along what is now the northern margin of the Pickering valley, a deeper water prevailed to the south, in which a scanty fauna existed, composed of the few species of mollusca that have been found in the Cement-stone.

This was the last change that took place in the episode that produced the Middle Oolites of Yorkshire; it was followed by a great and more universal depression, which let in again the waters of the Oxford Kimeridgian sea that had prevailed in the central district of England throughout the whole epoch. These waters, now become more thoroughly Kimeridgian in character, brought in a new fauna in which, under the altered conditions of their surroundings, but few species survived unchanged from the previous period.

Whether any interval of time elapsed between the formation of the sandstones and limestones of the Middle Oolite and the deposition of the Kimeridge Clay, during which the land was elevated above the level of the sea, we do not know. That this did not occur along the northern margin of the Pickering valley is proved by the perfect uniformity which exists between the two formations; but when we come to the southern side of the basin, in the country to the south of Malton, we are not so sure about the matter. Here the Kimeridge Clay rests on beds of various ages, from the Lower Calcareous Grit upwards. This is largely due to the thinning out of the intermediate beds, but whether the abrupt terminations of the outcrop of the Cement-stone can in all cases be attributed either to this or to faulting, or are the result of pre-Kimeridgian erosion, is not so clear. In this excessively disturbed district many of these appearances are caused by dislocations of the strata, but whether this is always the case cannot at present be decided; and therefore, whether the Middle Oolites were exposed to denudation previous to the deposition of the Kimeridge Clay, must be left an open question. Mr. Hudleston has suggested that the whole of the Vale of Pickering may have been a pre-Kimeridgian gulf, and that the present boundaries of the formation are on the site of old sea cliffs.* In our survey of the district, however, we have obtained abundant evidence that the Kimeridge Clay, where it does not naturally succeed to the lower rocks, is in every case bounded by lines of fault, which can be traced into the older formations at the head of the valley. Another proof, which may be adduced that the present boundaries of the Kimeridge Clay are not its original limits, is that nowhere does the formation show any evidence of a shore line, which must have been the case if these were old sea cliffs.

The Kimeridge Clay is capable of being divided into two or possibly three subdivisions or zones, showing that considerable time elapsed during its formation. In the early part of the period we find belemnites and oysters (*Ostrea deltoidea*) in great abundance, later on large numbers of ammonites and other mollusca came in, many species of which occur in the Oolitic rocks below, but modified by the altered conditions which surrounded them.

From the great thickness of the Kimeridge Clay and its nearly uniform character, it appears that little change took place in the physical geography of the country for some time, during which a large area was submerged, the limits of which we have no means of estimating; although, from the absence of anything like littoral deposits, they must have been far from the present outcrop. In many respects the physical conditions of the period resemble those that existed during the formation of a portion of the Lias, except that there was less calcareous matter deposited, and none of those great changes of level occurred which characterized the earlier epoch. Moreover a certain amount of bitumen also occurs in these clays, although not nearly so much as in the south

* Proc. Geol. Assoc., vol. v., p. 456.

of England, and Saurian remains have been found; both of which facts may be taken to indicate, as was the case during the Lias period, that land existed not very far off.

At the close of the period, although the physical conditions remained nearly the same, a change took place in the fauna by the introduction of many new forms some of which belong to the Cretaceous rather than to the Jurassic period, seeming to indicate that a passage exists between the two formations, and that the one succeeded the other without much interruption.

The whole of the deposits (Kimeridgian, Portlandian, and Neocomian) known as "Speeton Clay" have evidently been formed under very similar physical conditions, and at first sight have the appearance of being one continuous formation. But when we come to look at the fossils it is seen that they represent to a certain extent two very different epochs.

The question then arises how were these two periods separated from one another, and what took place in the north of England during the interval which produced so great a change in the palæontological character of the rocks in other districts. We may take it for granted that no very great change took place in the depth of the ocean between the Kimeridge and Portlandian periods, a certain number of new forms of life appeared, but there is no evidence of any break in the regular deposition of the beds, or that there was any interruption in the general uniformity of events. It is probable that the removal of some barrier let in the new group of ammonites and other mollusca which we find in the Portlandian clays of Speeton, at the same time that this area was cut off from that to the south by an upheaval ranging along a line a little south of the present northern escarpment of the Wolds. The recent observations made by Lamplugh on the clays at Speeton and by Nikitin and Pavlow on the Volga beds of Russia seem to show that there is a great similarity in the fauna of the two deposits, and suggest the idea that they may have been laid down in an ocean occupying the northern part of Europe.

This, which was the closing scene in the formation of the Jurassic rocks of the north of England, must have been followed by an interval of time during which the life of the period underwent that change which exists between the Jurassic and Neocomian fauna. The great similarity in the lithological character of the clays belonging to these two formations, and the diversity between their palæontological contents, is a fact of very great significance; tending to show that, although the condition of the sea bed was nearly the same during both epochs, an interval of time elapsed during which no sediment was being formed in this district. This may have arisen, either from the area in question having been above the level of the water, or from its being too far removed from the land to receive deposits.

Mr. Leckenby states that the upper part of these beds has the appearance of being the detritus of a previous deposit, which lends support to the former of these views. But if the surface of these strata was much denuded there would be greater evidence of uncon-

formity between the two, and consequently it is more probable that the northern area was in great measure beyond the influence of either denudation or deposition during the formation of the Portland beds of the south. There a great thickness of marine sands and limestones was being formed, of which in this district we have no trace. Mr. Lamplugh in his recent observations on the Speeton Clay also inclines to this view of the subject *; pointing out there is no evidence of unconformity between the Jurassic and Cretaceous beds at Speeton, but that "there has been an almost unbroken period of gradual deposition. proceeding at all times slowly, and occasionally all but ceasing," during which the Kimridge Clay to the west was denuded and may have supplied much of the material out of which the Portlandian and Neocomian beds were formed.

This brings us to the close of what we may consider to have been the physical history of this district during Jurassic times. The subject is one which necessitates a certain amount of speculation, but there are many facts which indicate the various changes that took place in the physical geography of the period. In these few pages we have attempted to point out the sequence of these events, and to give some account of their general character; and, although the subject has been treated very imperfectly, our efforts will not have been entirely in vain, if we have succeeded in drawing attention to this interesting branch of geology, and indicating in what direction further research may be profitably directed. "The aim and end of all geological work is: that it is not merely to tell us what rocks are like, but to enable us when we look at a rock to say how and where it was formed. When we can do this, Geology becomes not a mere catalogue of dry descriptions; but a history; and we learn to look upon rocks as the pages of a volume, on which is written an account of what was going on while they were being formed."†

* Quart. Journ. Geol. Soc., vol. xlv., p. 606.
† Green's Physical Geology, p. 287.

CHAPTER XVII.

SCENERY AND DENUDATION.

HAVING now traced out and described the various sub-divisions of the strata, which form this portion of Yorkshire, we may proceed to notice in what manner these alternations of beds of different mineral character, the movements they have been subjected to, and the denudation they have undergone, have affected the present physical geography of the district and determined its scenery. There is no subject more fascinating to the field geologist than the contemplation of the various landscapes brought before his view, and the study of the numerous agencies which have aided in their production. It has been stated that a knowledge of the scientific causes of things is detrimental to their æsthetic enjoyment, but if this is the case we think the evil, at least in geology, is more than counterbalanced by the pleasure derived from working out such hidden problems. These influences it is the endeavour of the geologist to discover, and by noting their present effect to trace out how far they may have acted in the past. The forces which have been instrumental in producing the general configuration of the ground are of three kinds—subterranean movements, denudation, and glacial action. Of these the former, beyond giving the beds their general inclination and producing a few minor rolls of the strata, has, in this district, had little to do in fashioning the present outline of the hills, except at certain places along the western side, where by producing large dislocations and thereby bringing beds of different character together, the general regularity of the contour has been somewhat altered. The second, which may be divided under the two heads sub-aërial and marine denudation, is the principal agent which has acted in producing the present outline of the surface; while glacial action, although it has produced some curious effects, as we shall see in the sequel, has had but little influence upon the general shape of the country.

The Jurassic rocks of Yorkshire form an isolated range of hills cut off from the rest of the county, and from the elevated ground composed of other geological formations, by a series of large valleys, which form the great lines of drainage of this part of England. From their peculiar geological construction these hills present a bold front to the north and west, overlooking the great plains of the Tees and Ouse; while to the south and east they gradually fall away to low ground beneath the escarpment of the Wolds, or are cut off by the sea. Owing to the basin-shaped form of the strata the greater part of the drainage of the district is towards the interior, and thence southwards by the gorge of the Derwent at Malton; the rest of the area, except quite the outer edge, which

gives rise to numerous small streams that either join the Tees or Ouse or flow direct to the sea, is drained by the Esk, which flows east into the sea at Whitby. The approximate area of ground covered by Jurassic rocks in these several districts is as follows:—

Drainage of the Derwent (within the Jurassic basin)	about	530	square miles.
„ „ Esk - - - - - -	„	126	„
„ „ Ouse (over Jurassic rocks only)	„	128	„
„ „ Tees „ „ „ „	„	70	„
„ by small streams direct to the sea coast	„	128	„

It is thus seen that the area included within the drainage of the Derwent is considerably more than all the other regions taken together. We shall point out presently, when we come to discuss the origin of the river systems of the district, why this is the case, and how the several areas of drainage have been determined by the position of the rocks. Of the above rivers the Derwent, the Esk, and the numerous small streams flowing to the sea belong particularly to this district, and rising in these hills, give life and beauty to its dales; the Tees and the Ouse, on the other hand, gathering their waters principally from the western mountains, receive merely the drainage of the outer edge; and although they have not now much influence on its scenery, have probably in former times been the chief agent in determining the western extension of these rocks.

Owing to the generally undisturbed character of the ground, and to the absence of Drift or any superficial accumulation over a great part of the area, the north-eastern part of Yorkshire forms a most instructive district, and one well adapted for teaching the first principles of physical geology. The connexion between the scenery and the denudation of the rocks is most marked; and, perhaps, there are few districts of England where the simplest forms of denudation are more clearly exposed than in the Tabular range of hills, and along the sea coast. We know of no more instructive lesson than is afforded by the series of tabular escarpments in the gorge of Newtondale, when viewed from the high ground above Levisham Station; or when standing on the high ground about Peak to look back along the coast towards the projecting promontories of Filey and Flamborough when these are lighted up by the evening sun. In all cases we plainly see that the character of the scenery is due to the elevation and denudation of the ground. The former by raising the beds, principally to the north, and in a less degree along the western and southern sides of the area has produced that peculiar basin-shaped form in which these rocks now lie. By this means the uppermost of the Jurassic rocks (the Kimeridge Clay) was raised in the neighbourhood of the Tees, and along the Vale of York, between two and three thousand feet above its present level in the Vale of Pickering, and the general inclination of all the beds in a south-east direction produced.

Although the elevation of the ground took place probably at several different periods, still the most marked disturbances evidently occurred at the close of the Oolitic, and again before

the commencement of the Upper Cretaceous epoch. By the first of these disturbances a ridge was formed in the neighbourhood of Acklam, which appears to have separated the Lower Cretaceous sea of the north from that of the south; while by a further elevation of the ground these deposits were extensively denuded previous to the formation of the Chalk. The earlier disturbance seems to have been the most violent and local in its action, the later elevation was less severe but more universal. The first of these produced the elevation along an east and west line parallel with the Howardian Hills, and was the main cause in giving the Jurassic rocks the basin-shaped form in which they now lie. The violent and sudden character of this uplifting of the strata along this range of hills was no doubt the cause of the numerous dislocations in this portion of the district. All the principal faults are parallel with the line of this disturbance, and are evidently due to the unyielding nature of the rocks to forces acting in this direction. The almost entire absence of any faults throughout the whole of the basin, except along its northern and southern edges, seems to indicate that it was principally at these extremities that the forces of elevation were exerted, while the general parallelism of the faults in these two areas would tend to show that they were formed at the same period, and therefore we may surmise that the northern and southern elevations are pre-cretaceous. With regard to the western elevation there is not much evidence to go upon. Beyond the western escarpment there is the faulted outlier of Borrowby, running in a north and south direction parallel with that escarpment; but whether these dislocations are of the same age as the east and west ones, or occurred at some other time, there is no means of ascertaining.* They are evidently the result of the western elevation of the Jurassic rocks, and we are inclined to think that they mark the disturbances of a later epoch, possibly the close of the Lower Cretaceous, when we know that the eastern part of Yorkshire was subject to great denudation. Some of the faults along the coast are even of more recent date than this, for instance, the Red Cliff fault affects the Chalk equally as much as the older rocks, and the same may be said of the Speeton fault, although it is beyond the district we are now describing.

Since the elevation of the ground denudation has planed off the higher strata, and caused the beds to crop out in regular sequence around the three sides of the basin on which they are exposed. By denudation we only refer to that which has produced the present surface of the ground. During nearly the whole of the Jurassic epoch some portion or other of the district was, as we have shown, extensively denuded; but, as we have treated of this in the chapter on the physical history of the period, we need now only dwell on that which has caused the present form of the country, and influenced its scenery. The inequalities of the

* Mr. Hudleston thinks that the Peak fault, with which these are parallel, may be partly of pre-oolitic age.

surface are almost entirely due to denudation; elevation, in this as in most other districts, has had little to do with fashioning the present contour of the ground. The higher tracts have not been raised into their present position by subterranean forces, but are the result of the cutting away of the surrounding ground, which has left behind the large masses of strata that form the existing ranges of hills, and although the disturbance of the strata has produced some minor inequalities in the more faulted districts, still the hills and valleys due to this cause will be found to be rather the exception than the rule. The present configuration of the ground is the work of the engraver of nature, although it is of course necessary that elevation should take place to enable it to bring its forces into action. "Upheaval has, as it were, raised the rough block of marble, but erosion has carved that block into the graceful statue." *

Denudation is, as we have said, of two kinds, sub-aërial and marine; the action of the former is to cut vertically into the strata, and to produce a more or less irregular surface, that of the latter to work horizontally, and form a generally plain or slightly sloping surface. When this district was first rising above the sea, it is probable that the action of the waves produced such a level surface, which may have been formed of the Cretaceous and other newer rocks, but we have now no evidence of the nature of this plain, or of how far marine action may have been instrumental in removing the superincumbent strata; the present inequalities of the surface, its hills and valleys, are entirely due to sub-aërial agents, such as rain and rivers, aided by frost and other atmospheric influences. These latter, by gradually weathering away the softer strata, have caused the harder beds to stand out in bold features, the principal of which, from the great thickness of some of the intervening clays, such as the Lias, the Oxford, and the Kimeridge Clays, are particularly marked. The rivers also, besides carrying away this dissolved and disintegrated material, have deepened their own channels, and formed the present open valleys and narrow gorges, which add so much to the charm and picturesqueness of the scenery. The courses of these valleys, their direction, form, and peculiarities, offer many subjects for reflection, but to this we shall return again presently.

The only evidence we now have of marine action is that afforded by the present coast; here the power of the waves and the manner in which they act is most clear and unmistakable. The softer strata, wherever they come to the level of the water, are cut back at a greater rate than the harder and more massive beds; thus the numerous promontories and bays which diversify this coast and are the principal cause of its beauty have been produced. If we examine minutely, either in the field or by the aid of a geological map, the various bays and headlands along the coast, we perceive in every case there is a reason for the particular form which the coast line assumes. Thus, commencing at the south, and taking only the more prominent features, we have

* Sir A. Geikie, Text Book of Geology, p. 911, 1882.

the great promontory of Flamborough Head formed of Chalk, which, although in some cases moderately soft, yet is so homogeneous in character, and porous in texture, that denudation has comparatively little action upon it, and consequently these cliffs project far beyond those formed of the soft clays on either side. The same thing occurs on the opposite side of Filey Bay; here the hard siliceous sandstone of the Calcareous Grit comes to the level of the water, and consequently runs out in a narrow promontory, from both sides of which the softer clays have been worn away.

Omitting the minor irregularities in the coast between here and Scarborough, at the latter place the Castle cliff affords a striking instance of the ability of a thick bed of sandstone to resist the force of denudation. Again, at Robin Hood's Bay, on account of the anticlinal curve into which the strata are thrown, the harder beds of the Middle Lias reach the shore, and protect the two headlands known as the North and South Cheeks, while the softer shales of the Lower Lias have been worn back to form this romantic bay. Further north the most projecting portions of the coast at Kettleness and Staithes are also formed of this rock, while at Huntcliff the comparatively soft Lower Lias shales stand out beyond the still softer Boulder Clay, which forms the coastline between there and Redcar. The form of the present coastline has been considerably modified by dislocations of the strata, which have brought down the harder beds to the sea-level in positions where, but for the fact of these faults, softer shales would have cropped out. This is the principal cause of the coast-line projecting at Scarborough and at Peak, and which according to the histories of the district does not appear to have been much worn away during the period of which we have any record.* It has been stated that the cliff north of the Abbey at Whitby has receded as much as 1,500 yards since the foundation of the monastry in 656.† This, however, must be an error, possibly from the fact of the site of the original building having been further from the sea than has been supposed. Were it not for faults, and their attendant rolls of the strata, the outline of the present coast would have been far more regular than it is. The most prominent headlands would have been where the harder rocks, which are succeeded by thick beds of shale, reach the shore, namely, above the Kimeridge Clay, above the Oxford Clay, and above the Lias. The two former of these have given rise to the headlands of Flamborough and Filey‡, the latter would have produced a prominent headland at Blea Wyke but for the accident of the Peak fault, which has protected this part of the coast, and

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* Hinderwell, History of Scarborough, pp. 53, 54; Young, History of Whitby, vol. ii., p. 738.

† N. J., vol. xxv., p. 241; Conybeare and Phillips, Geology, p. 273.

‡ The exceptional sharpness and narrowness of the Filey promontory may be due to the presence of a fault (probably the continuation of that at Brompton) on its southern side, which has brought down the Kimeridge Clay into closer proximity than it would otherwise have been.

prevented the Lias shales from being cut back to any extent Again, Cayton Bay, to the south of Scarborough, is entirely due to faults which have brought the Millepore Bed, the hardest rock of this part of the coast, to the level of the water at the two angles of the bay. North of Whitby the several picturesque bays and headlands seem to be due more to rolls of the strata than to actual faults.

The wearing away of the coast by the sea is much assisted by occasional landslips, which bring down the higher part of the cliff within the reach of the waves, where, from their loose and shattered condition, they are soon carried away. For this reason although landslips on a greater or less scale are constantly occurring at one place or another along the coast, it is only at a few spots where, from their greater extent, or from the harder nature of the rock brought down, that they leave any trace after a few years. The most important of these are in Cayton Bay, along the Staintondale cliffs, at Whitby, at Holms Grove* near Goldsborough, at Runswick,† and near Hummersea. At the first of these places the Calcareous Grit has been brought down, and forms an undercliff just north of the Pumping Station. Messrs. Young and Bird considered that this slip continued most of the way to Scarborough, occupying all the low ground between the Calcareous Grit escarpment and the cliff, and consequently they misunderstood the coast section between these places. It is, however, along the Staintondale cliffs that the largest of these subsidences has taken place; here, for a distance of over two miles, the upper part of the cliff has given way, forming a lower terrace, which is about 200 yards in width, and covered with loose blocks and irregular mounds, which frequently inclose small pools of water. On this uneven surface a dense growth of underwood has sprung up, which much enhances the beauty of these cliffs. South of Hayburn Wyke there is a similar undercliff, extending for nearly a mile, which is stated by Young and Bird to have been formed about the commencement of the 17th century. It is probable that both of these landslips affect only the upper part of the cliff, and that the shales which have caused them occur about the middle of the section, and not at its base; the beds along the lower cliff appear to be mostly in place, and are not a repetition of those seen in the higher cliff as has been supposed. The landslip at Whitby, which is in the Upper Lias shales, is constantly liable to move, and has done so recently, as is shown by the leaning position of some of the houses built upon it. The slip near Hummersea, although not of any great extent, is remarkable from the fact of the Ironstone Series having come down in a nearly solid mass, which lies with its upturned edges exposed to the waves, so that these beds, which would otherwise have been inaccessible, can be easily examined.

* Holmsgriff. Young and Bird, Geological Survey of the Yorkshire Coast, 2nd Ed., p. 150.

† This slip is stated to have occurred about 200 years ago.

Along the inland escarpments there are also several remarkable landslips. The most important of these are at Brockholes near Kirkby Knowle, and at Whitestonecliff. That at Brockholes occurred about the commencement of the present century, and exposes a clear section of a portion of the Grey Limestone Series and the beds below. At Whitestonecliff the slip is of much greater extent, and from the massive character of the overhanging rock, has produced a much grander effect. The sinking of the hinder part of the detached mass more readily than the front has formed a hollow in which the water rests, as is so often the case on a small scale; this is now occupied by Gormire Lake, which with the surrounding cliffs and woods has produced one of the most weird bits of scenery in this part of the country.

Here also we see that the general form of the ground, its hills and valleys, have been produced by denudation, which has carved out the valleys, and left the strata that compose the hills standing in their regular order of superposition. In this manner several portions of the Jurassic rocks have become detached from the main mass, and stand out as more or less isolated hills. Upleatham Hill, Eston Hill, Roseberry Topping,* Whorl Hill, the hills near Kirkby Knowle, and those near Hawnby, Freebrough Hill, Danby Beacon, Blakey Topping, Hackness, and many others are remarkable instances of this, while the general surface of the ground illustrates the manner in which these outliers are produced, and gives numerous examples of them in every stage of formation.

From its general physical character the area covered by the Jurassic rocks may be divided into three, or at most four districts, which correspond with the main geological divisions of the strata; —the low ground formed by the Lias along the northern and western margin; the high tract of land and swelling moorlands composed of the great estuarine and marine series of the Lower Oolite; the tabular range of hills of the Middle Oolite, rising to the south of these in a bold escarpment, and forming an elevated plain, which curves round to the south along the Howardian Hills; and lastly the low ground enclosed by these hills, in which the Kimeridge Clay crops out forming the Vale of Pickering.

The first of these districts, which includes a narrow tract of country usually averaging about four miles broad, lying at the foot of the Oolite hills, may itself be divided into three areas. The northern, constituting the plain of Cleveland, forms a low tract of land sloping gradually to the north from the steep escarpment of the Cleveland Hills to the banks of the Tees. Although the substratum of this district is formed by the Lias, it is only along the flanks of the hills that these beds are exposed; the rest of the surface is entirely covered with Boulder-clay and gravel. This ground was formerly devoted entirely to agriculture, but is now studded with numerous towns and villages, which the working of the ironstone in the neighbouring hills, and the manufacture of iron, have brought into existence or greatly increased. The western

* The ancient name of Roseberry was Ohtneberg or Hogtenberg signifying High Hill. Young and Bird, loc. cit., p. 214.

portion of the Lias is also much covered by Glacial deposits, although the lowest beds stand out in a low but conspicuous escarpment just east of Northallerton and Thirsk. This district forms a gently undulating country, overlooking the central part of the vale which is occupied by the Trias; it is rendered more hilly than it would otherwise be by the long faulted outlier of Borrowby, which rises in its midst. The third and southern area of the Lias is even more obscured by Drift than those just mentioned, and from this cause it is only with considerable difficulty that the several divisions can be made out. It forms a low range of hills, extending from Easingwold, by Stillington and Sheriff Hutton, to the Derwent, constituting the watershed between that river and the Ouse; east of this the ground becomes more free of Drift, and the Lias itself crops out in a narrow belt of heavy clay land, which runs out into a series of projecting ridges, between the numerous small streams that come down from the Chalk escarpment. On the whole, therefore, the Lias of Yorkshire partakes very little of the nature of a true Lias district, the heavy clay lands and level plains usually typical of the latter being considerably modified by the covering of Drift, which has formed a lighter soil and a more undulating country.

The Lower Oolite, which rises in a bold escarpment directly above the steep slopes of the Lias, produces a very different class of country. These hills along their northern and western edge attain a height averaging from 800 to 1,400 feet above the sea, they form a range of elevated moorlands, intersected by numerous deep valleys, along the sides of which the harder sandstones frequently stand out in lines of crags and bold cliffs, that render the scenery very wild and romantic. The general surface of these moors, if they were not so frequently intersected by large valleys, would be wild and desolate in the extreme, and even now in many parts the cold soil, scattered over with huge blocks of white siliceous grit, has a very dreary and dismal aspect. This is, however, soon dispelled when we come to the edge of one of the great valleys of the interior, and look down upon the cultivated slopes and snug homesteads nestled along their sides.

The above style of scenery applies chiefly to the country south of the Esk; north of that valley the Drift rises to a much greater elevation, and along the eastern and northern part of this district has completely altered its character. Here the old valleys have been mostly filled up, and a more uniform surface produced, which, although retaining the main features of the old pre-glacial contour, is now only broken by the narrow channels in which the present streams run. These usually form little wooded defiles between the gently swelling hills. The curious manner also in which two of these streams, when occupying the same old valley, run parallel with each other for long distances, with only a narrow ridge or Drift between them, is quite a characteristic feature of the country. The soil of the district is much improved by this superficial covering, consequently the land is enclosed and culti-

vated, and therefore more populous, although of course the great increase of population during recent years is due to the working of the ironstone.

The third great district is that covered by the outcrop of the Middle Oolite. This rises along the southern edge of that just described in a bold escarpment, which, at Black Hambleton, attains a height of 1,300 feet, but falls gradually towards the east to not more than 600 feet above sea-level. It forms a great spreading table-land, of which the northern portion is moorland; but being composed of porous sandstone is far drier than the moors, where the Estuarine beds of the Lower Oolite crop out. Towards the south the ground gradually declines, and higher beds come on, which consisting principally of limestone render the soil more fertile, and it is consequently enclosed and cultivated. The slope of the ground towards the Vale of Pickering is usually very regular; but where the beds are faulted up, as at Allerston, the change is more abrupt.

This table-land is cut through by a series of profound gorges, that at Langdale is nearly 600 feet deep, and only about half a mile wide at the summit, by which the rivers that gather their waters from the northern moorlands escape to join the main stream of the Derwent. The sides of these valleys are usually clothed with plantations, which considerably adds to their beauty; in some of the deeper gorges, where the lower parts are planted, while the upper is left open moorland, the contrast between the green foliage and the purple heather is very striking. At their western end these hills curve round forming the lofty plateau of Hambleton, which overlooking the Vale of York terminates in the grand mural precipices of Whitestone Cliff, and Roulston Scar 900 feet above the level of the plain. On the south these hills are sharply cut off by the peculiar faulted valley at Ampleforth, to which we shall refer again presently. Beyond this the Middle Oolites are again continued in an easterly direction to Malton, constituting what are known as the Howardian range of hills; a little to the east of which they pass beneath the escarpment of the Chalk, and thus complete the third side of the horseshoe with which these ranges of hills enclose the Vale of Pickering. Throughout the Howardian Hills the general dip of the strata is towards the north; so that the beds along their southern edge form a series of sharp features, which however are frequently interrupted by faults, and consequently the general regularity of the hills is more broken than in the northern area. In this district the several divisions of the Middle and Lower Oolites are also much thinner than along the northern and western ranges; for this reason the escarpments are smaller, and the contour less elevated, giving rise to a tamer style of country, but one more favourable for agriculture. The undulating character of the ground is well adapted to the formation of parks; and consequently the country is thickly covered with important residences, such as Newburgh Park, Gilling, Brandsby, Hovingham, Wigan-

thorpe, Castle Howard, Hildenley, and Birdsall, which cover a large portion of the area, and almost form one continuous inclosure.

The fourth and remaining area into which we may divide the north-eastern part of Yorkshire is the great valley extending from the foot of the Hambleton Hills at Helmsley to the sea-coast at Filey. This depression, which is known as the Vale of Pickering, is enclosed on the north, west, and south by the ranges of hills just described. It is drained by the Derwent and its tributary the Rye, which curiously enough, instead of flowing out at the open end towards Filey, has cut through the Oolitic hills to the south of Malton. The eastern portion of this valley is nearly a level plain composed of alluvial deposits; it is less than 100 feet above sea-level, and until improvements were made in the drainage was largely occupied by marshes. Towards the western end the Kimeridge Clay rises up from beneath the alluvium and forms a series of low but prominent hills which help to diversify the landscape.

With the exception of the last, these several regions are separated from each other by the main features of the district. These occur where there is the greatest geological difference between succeeding strata, for instance where a thick bed of porous sandstone succeeds to a considerable thickness of shale; by the weathering away of which the rock stands out in a bold feature overlooking the beds below. The thickest beds of shale are the Lias and Oxford Clay, and therefore it is just above their outcrop that we get the main features of the district. Where the Oxford Clay becomes very thin, or dies out, as in the south-west, the Calcareous Grit and Kellaways Rock come together in one great feature as at Whitestone Cliff and Roulston Scar; while in the Howardian Hills, where all the beds are much thinner, the escarpments are consequently on a smaller scale. The minor features of the district are also formed in the same manner, but from the several divisions of the strata being thinner, and from the difference in hardness between them being less, they are not nearly so strongly marked. The character of many of these beds is also very impersistent; so that, although they may make very conspicuous features at one place, they are entirely lost a short distance off. In fact with the exception of the main features just mentioned the only other beds that can be followed in this manner are the Kellaways Rock, the Grey Limestone and the Sandy Series of the Middle Lias. The higher divisions of the Middle Oolite are traced more by the character of the ground than by the actual features that they make. The mode of weathering of the several beds also produces a different contour, thus the Kimeridge Clay usually forms a flat or undulating valley, the higher beds of the Middle Oolite round swelling hills which repose on the flat table-lands of the Lower Calcareous Grit. This latter runs out into the great projecting nabs or headlands between the principal valleys and stream-courses that intersect the hills, and along the flanks of which the Oxford Clay forms a

steep almost precipitous bank. At the foot of this, which is the higher main escarpment, the Kellaways Rock forms a narrow terrace; this, from the strong jointing of the rock, and its tendency to run into hard concretionary masses, weathers into numerous small projecting nabs that are very characteristic of the rock. In some cases the Kellaways Rock covers a larger area of surface; this appears to be where the bed is thickest, or where from its position on a watershed the denudation is least. Beneath this the Lower Oolite forms a great spreading moorland, over which the outcrop of sandstones and shales occurs with apparently but little regularity, and having but few features that can be followed for any distance. The principal however of these is that caused by the sandstone known as the "Moor Grit" which nearly always forms a prominent bank, and enables the outcrop of the Grey Limestone Series to be traced with much greater facility than would be the case if this bed was absent. In the north-west of the area the fossiliferous grit, which is classed with the Grey Limestone, also makes a conspicuous feature, and forms a more gritty soil than any other member of the Oolite. With these exceptions the Lower Oolite generally forms a lofty undulating moorland, intersected by deep valleys, with here and there a bed of sandstone rising in a steep bank or line of crags which relieve the otherwise monotonous character of the ground. The basement beds of the Lower Oolite, which form the lower of the two main escarpments, are usually the most rocky part of the series, and give rise to a second lofty precipitous bank, which is occasionally, as at Battersby Crags, near the head of Bilsdale, and at a few other places, a vertical cliff. Below this the shales of the Upper Lias make a steep slope which gradually flattens out as it approaches the sandy beds of the Middle Lias that run out in a low terrace in those districts that are free from Drift; while below this again the ground gradually falls away in a nearly level plain towards the lowest portions of the Vales of York and Tees.

Although the tendency of all features is to run with the strike of the beds, or at right angles to the dip, it is only in a general manner that this direction is maintained. The regularity of the escarpments is frequently broken by the intersection of the large valleys, which cut across them, and cause the features to bend round on either side, so that their direction is in many cases altered. These valleys play an important part in the physical geology of the district, and are the principal cause of the peculiar character of its scenery. We may, therefore, consider how these valleys were formed, and why the streams chose the particular courses in which they flow at the present time. It is now generally admitted that narrow winding valleys, such as these which intersect the Oolitic rocks, were formed by the streams which flow through them, and are not the result of fracture or marine erosion; but it is not so clear to the ordinary observer how they manage to cut through great escarpments, or why, when they apparently have a clear open course to the sea, they frequently choose a more indirect and

difficult route. On looking at the map it will be observed that the greater number of rivers cross the large escarpments; in fact, with the exception of the Esk, all the larger streams flow south, and cut through the range of hills formed by the Middle Oolites, producing gorges from 500 to 600 feet in depth. If these gorges did not originate in cracks or disruptions of the strata, of which there is certainly no evidence, they must have been formed by the denuding power of the stream; but it is not so clear at first sight how they could have breached the line of bold hills standing in their way. This difficulty is however got over when we remember that some streams must have commenced to flow as soon as the ground rose above the level of the sea, and before the present inequalities of the surface were produced. These would naturally follow the inclination of the ground, which would coincide with the general dip of the beds, varied here and there by local rolls of the strata. This is just what occurs in the present case. South of the Esk watershed, the general dip of all the strata is inwards or towards the centre of the horseshoe in which they are arranged; this consequently is the direction of all the streams, with the notable exception of the Derwent at Malton, to which we shall refer again presently, and it is evident that their initial direction was given them when the ground uniformly sloped in that direction. Whether this surface was composed of Cretaceous rocks, Kimeridge Clay, or merely the harder beds of the Middle Oolite is immaterial; either of these formations, if they extended to the northern limit of drainage, would produce a slope in the same direction as that of the present rivers. The streams thus once begun would continue to deepen their channels at a greater rate than that at which the intervening ranges of hills were cut back by purely sub-aërial waste; and thus the courses first chosen would be retained, although they may now appear to be the most difficult.

Nearly coinciding with the northern limit of the Derwent drainage is a great anticlinal axis running from the moors west of Burton Head across the higher ground to the coast at Robin Hood's Bay. North of this line the strata roll over and dip towards the north; and, although the uniformity of dip is occasionally interrupted by minor axes of elevation, the general inclination is in that direction. For this reason the whole of the drainage north of the anticlinal flows north or east to the sea-coast, and is entirely separated from that of the Derwent and its tributaries. In some cases a valley running south appears to be connected with one falling in the opposite direction. A good example of this is at the summit level of the Malton and Whitby Railway, where it crosses over from the Newton Dale valley into that of the Eller Beck. Both of the streams which flow down these valleys rise in bogs or peaty swamps at the summit of drainage, the former in Fen Bogs, the latter in May Moss; but the source of the Eller Beck is 300 feet higher than that of the Newton Dale stream. The most curious circumstance, however, connected with the flow of these streams is that the Eller Beck,

after a course of over two miles in a well-formed valley, flows across the end of Fen Bogs at the head of Newton Dale, and instead of continuing down that valley, turns north to join the Esk. Let us now consider how this anomaly may have arisen. If we trace the watershed on a map we observe that the line makes a considerable bend to the south, where it crosses the head waters of the Eller Beck at May Moss, and consequently the source of this stream is a long way to the south of the anticlinal axis, which we have mentioned as parting these two water-systems. If the initial direction of these streams was, as we have stated, originally determined by this axis, it is evident that the Eller Beck cannot at first have joined the Esk; how then came it to do so, and to flow across the head waters of another stream. Except from the blocking up of its course by glacial action, from the production of open fissures, or from the alteration of the level of the surface by subterranean movements, the only manner in which a stream can cross a ridge is by gradually cutting its way backwards, and this is the way we would suggest that the alteration in the course of the Eller Beck has been brought about. The head waters of this stream originally flowed through the hollow now occupied by the Fen Bogs, and down Newton Dale; but as the lower part of the course, which was then a separate stream, cut its way back, it tapped the higher waters, and converted them along the northern channel, while the Newton Dale stream, being deprived of the upper portion of its drainage, formed its present source, when from the lack of denudation the growth of peat took place.

Another instance of the alteration of an old stream-course, but arising from a totally different cause, is that of the valley of the Derwent below Hackness, and again at Malton. In both of these cases the the river forsakes an apparently open valley to the east, and cuts its way south through narrow defiles in some of the hardest rocks of the district. There can be but little doubt that in each instance the larger valley was at one time open to the east, and such would even now be the case if the Boulder Clay and other superficial deposits which cover the solid rocks were removed. In the first case, from the gradual increase in width, it is evident that the great open valley along which the New Cut is carried towards Scalby is the continuation of that of the Derwent at Hackness.* The width of the present valley of the Derwent above where it turns off from its old course is about 1,100 yards; that of the old course between Seamer Moor and Hackness Hill is 1,700 yards; while the Forge Valley down which the river now flows is only between 400 and 500 yards wide.† Thus we see that the present gorge of the Forge Valley is only about a quarter of the size of the now disused valley running to the east,

* The colouring of the six-inch geological maps renders this very apparent, and if the two sheets 77 and 93 be placed together the difference in size between the Forge Valley and that running towards Scalby is very striking.

† These measurements are taken from the edge of the escarpments overlooking the valleys.

although both are in a similar class of rocks; and therefore either the river must have been larger and more powerful when this valley was cut out or it must have taken a longer time in its formation. We have observed that all the rivers traversing the Tabular Hills flow south, how then was it that the Derwent should have an easterly trend given to this part of its course. The explanation seems simple enough. All the streams had their initial direction given to them by the inclination of the strata, which was southerly, but here this general uniformity is interrupted by a roll up of the beds along an anticlinal axis running from Lockton to Scarborough;* this would naturally have the effect of turning the waters along its course off to the eastward, and in this manner it is probable that the easterly direction of Troutsdale and this portion of the Derwent was brought about. The most curious point however in connexion with this old valley is not how it came to be formed but how it was that the old course of the river was altered and diverted from this channel. This could only have been brought about in two ways, either by the upheaval of the ground to the eastward, or by an accumulation of Boulder Clay blocking the channel in this direction. The first of these suppositions is very improbable, while there is abundant evidence that large masses of Boulder Clay have been deposited over the lower ground between here and the coast. These at present cover the whole of the lower ground to the eastward, and in places are of great thickness, there being as much as 200 feet exposed in the sea cliffs, and it is supposed that there are 100 feet more below that level at Scarborough. There is no doubt that these beds extended some way further seawards, and probably rose to a greater height than they are now found. The summit of the escarpment at the entrance to Forge Valley is only about 430 feet above sea-level; this is considerably below the level at which we still find patches of Boulder Clay on Seamer Moor, and at Suffield, so that if the gound to the east were filled with glacial deposits to this level, or even if the North Sea were held by a large body of ice, as it must have been during the glacial period, the waters of the Derwent would be dammed back, and forced to overflow the escarpment at the lowest point, which is where the Forge Valley now is. There is also additional evidence of the post-glacial age of this valley from the fact of it being entirely free from Glacial beds, while the great valley to the east towards Scalby, and that by which the railway approaches Scarborough are both filled with these deposits. It is quite possible that the original course of the Derwent may have wound round by these valleys, and so reached the Vale of Pickering east of Seamer; but whether it did so, or entered the sea near Scarborough, is not very clear; it is very probable that the course of this river has been altered more than once, and from the great depth of the Boulder Clay at Scarborough it would seem that it once lay in

* Memoirs of the Geol. Survey. Explanation of Quarter-Sheets 95 S.W. and S.E., p. 41.

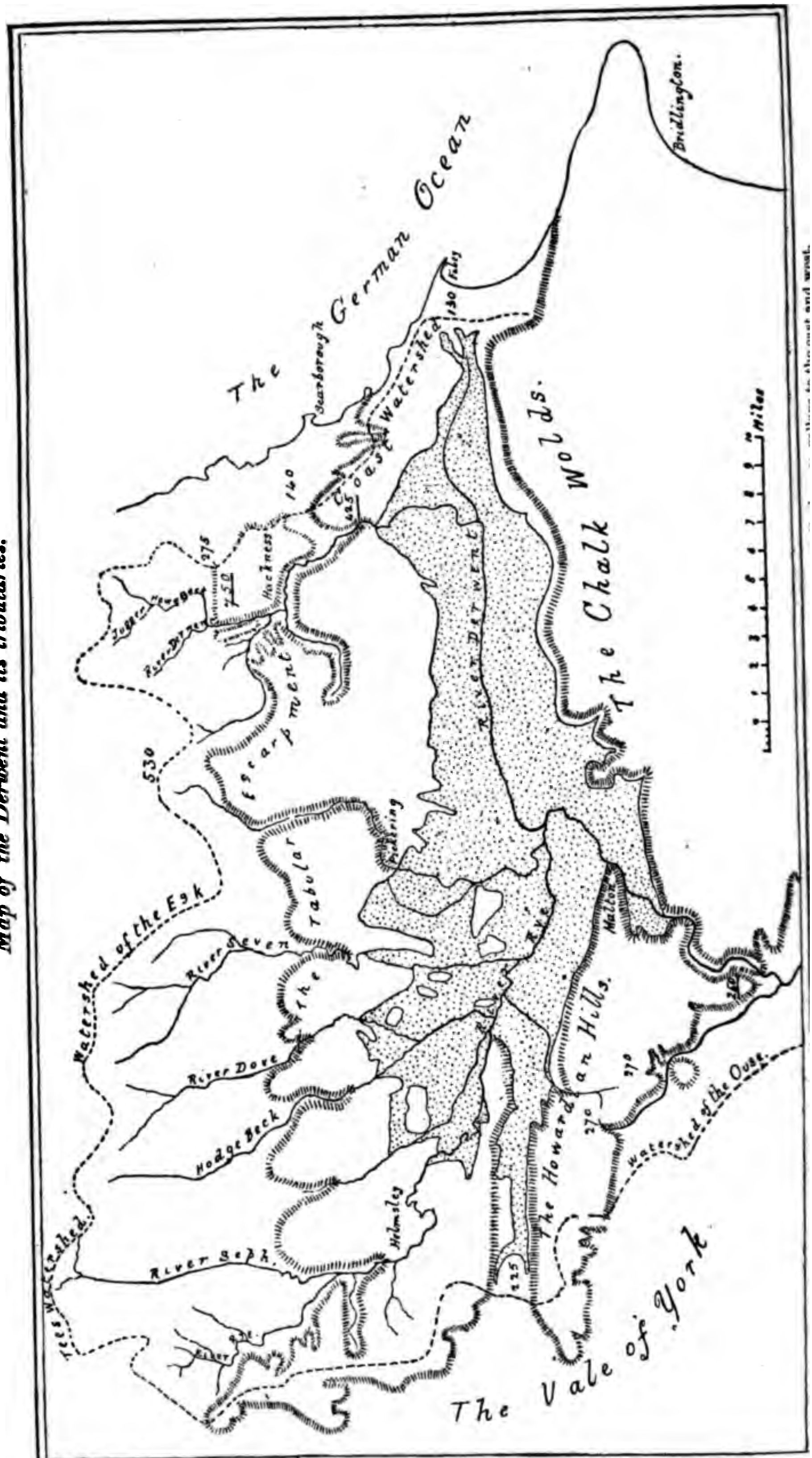


FIGURE 22.
Map of the Derwent and its tributaries.

that direction. The following quotation from Leland (fol. 49), showing that the drainage of this district has been altered by natural agencies within historic times, is curious, "The commune opinion ys yet that part of Darwent Water ran to Scarburge, but by excaving of two sides of hilles, stones and yerth felle in great quantitie doun and stoppid that course." Of course this does not refer to the great pre-glacial valley we have been describing, but probably to the overflow of the Derwent into the Scalby Beck; which channel has, in more recent times, been again opened out by the drainage works in connexion with the New Cut.

The gorge below Malton seems to have been formed in a similar manner to the Forge Valley, but with this difference that an older stream course probably existed on the same site. This stream, from the northerly dip of the beds here, would originally flow north into the Vale of Pickering, as is the case with the Wath Beck near Hovingham and other streams in these hills; but from the limited area of drainage it would not have been any larger than these streams. Now if we suppose the eastern end of the Vale of Pickering to be blocked by Boulder Clay the drainage must naturally find its way out at the lowest point; this appears to have been at the head of the little valley which we suppose to have occupied the position of the present course of the Derwent below Malton. By gradually lowering the higher part of this valley it would in course of time change its slope to the opposite direction, and eventually drain the Vale of Pickering which during this period must have been a lake. That there is nothing impossible in this reversal of the stream below Malton is seen when we examine the levels of the different watersheds. The edge of the escarpment, where it is cut by the present valley at Kirkham is between 200 and 250 feet above sea-level; the level of the Boulder Clay, which now blocks the Vale of Pickering near Filey, is 130 feet; so that it only requires the Glacial deposits along the sea-coast to have been about 100 feet thicker to have sent the water over the depression to the south of Malton. As an instance of how easily this may be accomplished we may take the case of the Wath Beck; here the level of the watershed, separating it from the Vale of York, is about 250 feet above sea-level; consequently, if the watershed at Malton had not been slightly lower, the drainage must have escaped by this valley, and the course of this stream would have been reversed, and have flowed towards the Vale of York instead of northwards to the Vale of Pickering as it now does.*

If this latter valley was a lake for any length of time there should be some proof of a shore line either in the form of gravels or terraces along its margin. Although these have been mostly swept away by subsequent denudation there is still some evidence of their former existence. The most marked terrace at the present time is that on the north side of the valley at Hutton Bushel, the

* The Gilling erosion has no connexion with the river-systems of the country, and is probably of later date than any of these river gorges.

level of which is a little more than 200 feet above the sea, that is exactly at the level that a beach would be formed when the exit from this lake was across the hills south of Malton. Below this there are two minor terraces not so well marked at about the 100 and 140-feet contour, which probably denote periods during which the denudation of the Malton gorge was for a time checked. Besides this there are no distinctly-marked terraces, but there is a considerable amount of gravel here and there, all of which is below the 250-feet contour.* The fact of the Kimeridge Clay, over the western end of the valley, rising into hills which are readily denuded, and the sides of which are constantly slipping, may account for there being no terraces or evidence of a shore-line in this direction.†

Besides the important instance of the Derwent there are several cases in which the minor streams of the district have altered their courses. The principal of these is the Settrington Beck below North Grimston, which originally flowed westwards across the Oolitic limestone to Auburn Hill; but now has abandoned that course, which is a dry valley of over three miles in length, and flows due north to Settrington. What was the cause of this alteration is not very clear, but it appears to have been effected by the denudation of the Kimeridge Clay between here and Malton, previous to the formation of the alluvial terrace which now covers that ground. If this was the case it is very probable that the short valley, which crosses the Oolitic ridge at New Malton, and which is exactly opposite to Auburn Hill was the original mouth of the Settrington Beck. There is also an old valley at Peasholm just north of Scarborough that has been excavated by some stream which has now abandoned this course. Very likely this valley was the continuation of Scalby Beck, which has had its course shortened by the denudation of the sea, as will probably happen again before long above Scalby Mill. Another abandoned valley is that on the eastern side of Oliver's Mount, called Deep Dale, which must have been formed by some stream larger than that now flowing through it. In this case also it is evident that the denudation of the coast has, by curtailing the gathering ground of any stream that could flow through this valley, brought about the change.

The only other valley, within the area of the Derwent drainage, which presents any peculiarity is the hollow between Gilling and Coxwold. This does not appear to have been formed by any river, but to be the result of purely sub-aërial waste, possibly aided at one period by marine action to some extent. It is in fact a remarkable instance of a faulted valley, its presence being entirely due to the fact that the softer Kimeridge Clay is here faulted

* There are indications of gravel terraces just above the 200-feet contour at Allerston and other places, but they are mere fragments and not sufficiently distinct to show on a map.

† The fact of the Vale of Pickering having been a lake or an estuary has been noticed by Dr. Buckland, Prof. Phillips, and others; but these authors did not produce much evidence in support of the statement.

down between the harder beds of the Middle Oolite, which rise up on either side in bold escarpments, and is more readily worn away than these massive rocks. This we consider to have been of later date than the other valleys connected with the Vale of Pickering, for although the present watershed here (225 feet) is about on an equal level with the escarpment south of Malton, and therefore does not affect the theory of the formation of that valley; still even if it were lower the softer character of the Kimeridge Clay would cause it to be denuded away at a greater rate than the Oolitic rocks, and therefore it need not have existed at the time when the Malton gorge was opened.

Many of the streams which enter the Vale of Pickering, especially on the north side, flow underground for some distance. This occurs wherever the large valleys crossing the Tabular hills pass over the outcrop of the oolitic limestone in the upper part of the Middle Oolite. Here the streams by gradually dissolving away these calcareous strata have formed underground channels in which a part or the whole of the water is now diverted, the original course at the surface being dry except during wet seasons. This is the case with all the streams between Helmsley and Pickering; for instance a portion of the river Rye sinks a little above Helmsley and comes out near Rye House more than a mile below. The Riccal begins to disappear about a mile north of the Helmsley and Kirkby Moorside road, and rises again some distance south of this road. The Hodge Beck is lost soon after passing Hold Caldron Mill, and rises again in the deep basin of Howkeld Head more than a mile below and a third of a mile east of its old channel. The Dove enters the rocks just below Yoadwath Mill and comes out again at Spring Head about half a mile lower down. Hutton Beck sinks about a mile and a half above Catter Bridge, a little below which it rises again under the new name Catter Beck. The river Seven also sinks above Sinnington and rises again gradually along its old course below that village. Besides this there are the important springs of Keld Head near Pickering which is the source of the Costa; the large spring at Brompton which is sufficiently powerful to work a mill; the swallow-hole at Ayton, of which an account is given at page 492; the copious spring at the end of the Ness promontory; the Lady's Spring at Malton, and many smaller streams which all mark the exits of underground channels by which the limestone of this part of the country is riddled. In this district most of these are formed in the Upper Limestone, along a line where the beds are more argillaceous than elsewhere; and which from the irregular surface of the limestone forms a marked horizon known to the quarrymen as "hilly and holey." In course of time, from the valley at the entrance being deepened and from other causes, the water becomes diverted from these underground channels, and small caves are left as we now find them about Helmsley and Kirkby Moorside. The most celebrated of these is that at Kirkdale, which is about 60 yards long, and the entrance to which is

about 30 or 40 feet above the present stream-course. In this cavern, which appears to have been a hyæna's den, the bones of many animals have been found.* Other caverns exist at Kirkby Moorside; in Duncombe Park; and in Riccal Dale, but they have not attracted much attention.

It is probable that in a similar manner, that is from the dissolving of the limestone by water, the peculiar configuration of the east branch of the Yedmandale, long ago noticed by Mr. Sorby,† was brought about. This valley, which has no stream in it, is about two thirds of a mile long. About a third of the way from its head there is a circular depression called Kimlin Hole, which is about 15 feet deeper than the valley; while about 400 yards below the valley makes a sudden drop of over 50 feet. These depressions have been attributed by Mr. Sorby to denudation produced by currents acting on the surface; but it is not usual for currents to cut out circular holes on a large scale. It seems to us much more probable that these depressions are due to the dissolving power of the water, and that they have been formed at those points where the valley crosses an open joint or fissure. Kimlin Hole is nothing but an ordinary swallow-hole which has become filled up with detritus; the second depression has also probably been a larger swallow-hole from which the lower or southern side has been worn away, so that now it forms an open ut deeper valley.

We will now turn to the valleys north of the Derwent watershed. There is here far more Boulder Clay than in the district we have been describing, and the manner in which it has filled up, and in some cases entirely obliterated, the old preglacial valleys, is very remarkable. With the exception of the Leven, and some other small streams flowing into the Tees, the whole of the drainage of the district is carried direct to the sea, either by the Esk flowing east or by the numerous small streams flowing north. As we have explained was the case with the Derwent and its tributaries, so no doubt here the initial direction of the streams was produced by the original slope of the surface. This from the elevation of the ground along the major axis cutting off the Derwent, was on the whole towards the north-east, but its regularity has been disturbed by several minor rolls which produced inequalities that deflected the Esk, and some other streams from this general direction. Owing to the Drift-covered character of the ground, and the very slight amount of these disturbances, it is not easy to trace the direction of the undulations, and therefore their effect upon the strata is not always very clear. For instance it is difficult to see why the Esk flows east instead of north. The strata on the south side of the valley are dipping north at a high angle; but those on the north side of the valley are also dipping north, but in a much less degree, and in many cases appear to be

* *See* Phillip's Geol., Yorkshire, 3rd Ed., p. 168.

† Quart. Journ. Geol. Soc., vol. x., p. 328.

almost flat. A slight elevation along this side of the valley would convert this northerly dip into a southerly one, and form a ridge that would divert the waters coming down the dales on the south side in an easterly direction. That something of this sort has taken place seems to be implied from there being still a slight anticlinal roll running from Guisbrough Moor in a south-easterly direction, which points along the northern edge of the Esk valley, and in former times may have been more apparent than it is now.* The other streams of Cleveland all follow the natural inclination of the ground, which is to the north-east; except the few short streams on the west, which probably had their origin beyond the escarpment, and have gradually eaten their way back; so that in the two principal cases, that of the Leven and the low ground near Guisbrough, they form continuous valleys with the Esk and Skelton Beck respectively. In the latter case the denudation of the valley has probably been aided by the Upsall and other faults in that district.

The chief peculiarity in the Cleveland streams is the manner in which they have altered their courses since the ground became overspread with Boulder Clay. An account of these old valleys is given by Barrow in the memoirs descriptive of North Cleveland and Eskdale, from which the following information is taken† :—

These Drift deposits have played an important part in modifying the general features of Cleveland, having completely changed the character of the valleys, and even altered the direction of the flow of the streams; one of the most characteristic points in the scenery of the district being the extraordinary number of rock gorges through which the streams flow, and which are in all cases simply due to the blocking of a pre-glacial valley by Drift. These old valleys, as may be shown over and over again, are considerably deeper than the present ones, and affect both the largest streams in the district and the smallest hollows. For instance, in the bay west of Whitby, the Drift is obviously below sea-level, for it is found by dredging that the bottom is strewed with big boulders, and no rock is known to exist there. It is, however, from mining evidence that we get the most conclusive evidence of these buried valleys. A series of borings just to the west of this area proved the old Tees valley to be 90 feet below present high-water mark. Indeed, one boring was said to go more than 200 feet into Boulder Clay, but there is little doubt that the greater part of this was the New Red Marl. In Tockett's mine a level was driven from the pit bottom, which, after being in rock for some distance passed for a 100 yards in loamy sand, thus proving an old valley; which, from a series of borings in the royalty and at the south end of Upleatham Hill further east, was found to be nearly 100 feet below the present stream (Ellers Beck). A similar state of things

* In this district the synclinal axes are more marked than the anticlinal rolls Mr. Barrow in his description of the country seldom alluding to the latter.

† Memoirs of the Geological Survey: Expl. of Quarter-Sheets 104, S.W., S.E. pp. 68-71; and Expl. of Quarter-Sheet 96, N.E., pp. 51-53.

is proved by the shafts in the Boosbeck Valley, and, in fact, in every instance where mining operations have been carried on across these valleys.

Where the old and new valleys coincide the stream-courses are cut in Boulder Clay, without any rock showing. But occasionally the mass of Drift is so great as to turn aside the rivers and force them into new channels. Thus the Esk sometimes leaves its original course and cuts its way through the solid rock, as at East Arnecliffe Wood and Crankly Gill. Here the difference in the size of the valleys is at once apparent; the new valley is a mere steep-sided gorge, in Crankly Gill only 150 yards wide, while the corresponding ancient, and perhaps pre-glacial, valley filled with Drift, is about three quarters of a mile across. The depth of the Boulder Clay below the present bottom of the valley can only be ascertained in two or three places. At Grosmont Mine it is about 45 feet to the rock; at Glaisdale Mines, 53 feet; and at the Tile Works close to Easton Lane in Little Fryup a boring was put down about 60 feet in laminated clay without reaching the Lias. In the last case the surface level is about 30 feet above the Esk. Though it is impossible to say that these sections coincide with the deepest part of the old valley it is probable that they are not far from it. The depth may therefore be calculated at about 50 feet below the present stream.

The lower part of the valley of the Murk Esk from Hazel Head northward is filled with Drift, principally Boulder Clay, which also spreads in a thin sheet over a considerable area of the moors around Julian Park, rising to a height of about 700 feet. Near Julian Park the Drift has forced the Murk Esk to cut a new channel south-east of the old one, and separated from it by a hill of Lower Oolite. At the top of Combs Wood a section shows coarse Boulder Gravel, resting on Boulder Clay. The Boulder Clay is probably thickest where it fills up the course of the Eller Beck, which once flowed almost exactly along the line of the old railway.

The lower portions of Egton Grange and Glaisdale are both filled with Drift, and the symmetrical shape of the dales destroyed by high irregular mounds of Boulder Clay. In Glaisdale, as already noticed, the accumulation has been so great as to force the Beck to cut a new channel.

These facts show at once that if a stream cuts through the rock anywhere, it can only be because it is flowing to one side of its old course.

Returning again to the river Esk we find that at Ruswarp it is approximately in the centre of its old course, and shows no rock. But further north it begins to flow between steep rock banks, which, near Whitby, are nearly vertical. Its pre-glacial course was across the large alluvial flat and into the sea, where the cliffs are entirely composed of Glacial deposits. A deep well sunk in this old line of flow went down a great depth without meeting with any rock, but the exact details we were unable to obtain.*

* These pre-glacial valleys are well shown in the Horizontal Sections of the Geological Survey, Sheet 130.

The two branches of Raithwaite Gill flow partly in the old line of valley, but as they near the sea, the western one has evidently cut out a new rock channel. The old valley passing through Mulgrave Woods was originally drained by one stream, but now two flow through it, kept apart by a narrow ridge of Drift, on which Mulgrave Castle stands. This ridge is being rapidly denuded away, and in some places, the two streams are so close that their reunion does not seem far distant. As might be expected, the north bank of the north stream, and the south bank of the south stream, both often present steep rock faces, the denudation having begun on the two flanks of the old valley. It is from the fact of the water finding its way more readily along the sides of these clay-filled valleys, and cutting into the solid rocks along the line of junction, that has given rise to the numerous parallel stream-courses which are so common a feature of this district.

It is, however, in connexion with Runswick Bay, that we see the greatest change produced by the blocking effects of the Boulder Clay. The streams at present flowing into the sea here are so small that they are manifestly incompetent to have cut out the large bay, and we must look for its cause elsewhere.

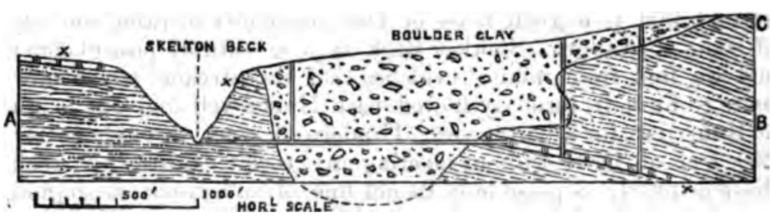
At Staithes a considerable stream flows out to sea, and following it inland we find, at first, its sides are almost cliff-like in character. The rocky banks become lower as we approach Dalehouse, and beyond that is a great mass of Drift, evidently marking the site of some old valley. Staithes Beck then is entirely post-glacial; and we find from mining evidence that the streams which now unite to form it, formerly flowed past Hinderwell and out to sea at Runswick, for a boring near Hinderwell went through nearly 200 feet of Drift without meeting any rock. Borrowby Beck flows as nearly as possible in its old line of valley, but Easington and Grinkle Becks repeat the phenomena seen in the Mulgrave Woods, each flowing at one edge of the old valley, and having a ridge of Drift between them. The short tunnel on the Grinkle mineral line pierced this ridge a few feet only above the stream. It was driven entirely in the loamy sands of Middle Glacial age, which, as usual, were found to be "quick." It is evident that the whole of the Lower Boulder Clay beneath would have to be sunk through before reaching any rock. The stream flowing into the sea at Skinningrove, which now divides into two at Liverton Mine, formerly split up further north, and the course of the eastern valley was proved in one of the new engine-planes, driven across it in Lofthouse Mine. Lofthouse Beck, which flows roughly parallel to, but south of, this line of old valley, is cut entirely in rock. The most picturesque example of these geological phenomena is seen in Kilton Beck. Here the stream has deviated considerably to the east, as is well shown by the outcrop of the Grey Limestone. The Moor Grit, immediately above the last-named bed, is a very massive rock, and the east side of the valley is consequently capped by bold crags for more than a mile, both sides being densely wooded.

Hagg Beck keeps mainly to its old course, but in Avens Wood and Girrick Wood are fine examples of gorges cut in the Estuarine shales. The great Boosbeck Valley has been so completely filled with Drift deposits as to force the stream that eroded it to cut an entirely new course, forming for itself a channel through the solid rock at Slape Wath, whence it flows by the west side of Skelton Hill into Ellers Beck, and so to the sea.

The most interesting example of a pre-glacial valley occurs near Skelton Beck, the former position and extent, and approximately the shape of the old valley having been proved in mining operations. A long level was made from Marske Mill, first in a south-westerly direction, and then turning a trifle east of south. This was driven through Drift deposits for a distance of nearly 900 yards, so as to pass under a series of borings, which had already revealed the fact that an immense mass of rock was absent, and its place to a great depth taken by clay, sand, and gravel.* The ground at the surface does not give the least indication of the great valley beneath, which, when occurring on so large a scale as this, is unusual. The explanatory diagram (fig. 23), in which the vertical

FIG. 23.

Pre-Glacial Valley in Skelton Beck.



Vertical Scale about three times the Horizontal.

C Estuarine Series. × × × Main Seam of Ironstone.

A B Lias Shale.

scale is three times the horizontal, shows at a glance the relative sizes of the ancient and modern valleys. The position of the central parts of the former is made about 90 feet below that of the latter, repeated borings in this valley have shown this to be approximately the difference in depth between them.

One of the strangest facts brought out is the overhanging bank of Alum Shale, which was proved in what is, in consequence, known as the cliff bore-hole. The diagram shows this very well, but the exact amount of projection could not, of course, be proved.

A small branch of this old Skelton valley was proved in Tockett's Mine. The main level into the Upleatham royalty cut through a "wash," about 150 yards long, the central part of

* This is the phenomenon so often called "Clay Wash" by miners and engineers It is, of course, a pre-glacial valley.

which was filled with a sandy loam. The sides were composed of strong clay, resting in either case against a steep rock face. This level is here about 70 feet below the bottom of the modern valley close by, but obviously it does not reach the base of the old valley, which must be somewhat deeper.

Phenomena similar to these may be met with in the district around Guisbrough, but they call for no special notice. The only other modern gorge of any interest, is that of the Leven in Kildale, which is extremely beautiful. Its post-glacial age is very apparent, the central part of the old valley being completely blocked with gravel.

From the foregoing account it may be observed, that all the principal streams of the district have, to a greater or less extent, altered their courses; which as a rule are cut in rock gorges, but not to so great a depth as the old valleys.

At Boosbeck we have an instance where the blocking of the old valley by Boulder Clay has caused the stream to cut a new course across the escarpment, and to flow west instead of east in a similar manner, but on a smaller scale, as we have mentioned has been the case with the Derwent.

Before closing this chapter we may say a few words on the distribution of the Boulder Clay. This, as we have shown above, is very partial, only occurring over the northern part of the district, and along its east and west flanks. It covers a great part of the country north of the Esk; but neither over the high moorlands south of that valley nor throughout the Tabular Hills, with the exception of a doubtful patch near Cropton, has any been found till we reach the lower slopes bordering the Vale of Pickering, where it appears to be mostly of local origin and a very different material from the genuine Boulder Clay which surrounds these hills. Unless we are to suppose that the whole of the Boulder Clay has been swept off the central part of the area, it would seem as if the Jurassic rocks had during this period formed an isolated region above the influence of glacial action. Along the northern flank of this high ground the glacial deposits rise to a height of from 600 to 850 feet above sea-level, but on the east and west sides their altitude gradually declines towards the south. From this it would appear that the ice coming from the north pushed up over these hills nearly to the high ground now forming their central axis; by which it was divided into two streams, one passing west down the Vale of York, the other east along the coast. The manner in which the glacial beds hug the coast is most remarkable, never extending more than about three miles inland, although they sometimes rise to a considerable altitude, as on Seamer Moor, where they are 600 feet above sea-level, and again at Speeton, where they cap the highest part of the Chalk at a height of 450 feet.

The Vale of Pickering may during this time have been held by a local glacier; for although there is a considerable amount of Boulder Clay in this valley, it appears to be mostly derived from the Oolitic rocks themselves. The only deep section we have

seen in these beds was in the railway cutting near Thornton Dale, where it was composed mostly of large calcareous doggers and great masses of Kimeridge Clay, both of which occur in the immediate neighbourhood.

The effect of this partial distribution of the Boulder Clay has been to render the scenery of the northern or Cleveland district much tamer than that of the central hill ranges. The Boulder Clay districts being usually inclosed and cultivated, the landscape becomes diversified by trees, which affords a striking contrast to the heather-clad slopes and rocky banks of the more elevated moorlands.

Since the Glacial period the general aspect of the country has not undergone much change; the main lines of drainage previously determined have not been altered except locally in the manner we have pointed out; but many of the old streams have been divided into two; and, in all cases where they occupy their original courses, they are smaller than the old pre-glacial valleys. The greatest amount of change since the Glacial epoch has probably occurred in the Vale of Pickering. Here we have superficial deposits reaching a thickness of 90 feet, and mostly composed of fine clays and sands with a little gravel, which we believe to be of post-glacial age. These beds form a nearly level surface, which covers the greater part of this large valley, and must have been laid down at a time when this depression was either a lake or an arm of the sea.* It is quite possible that a great portion of these beds were formed when this valley was an estuary; but the finishing touches, so to speak, were given to it after the Glacial epoch, when the drainage of the eastern part of the valley was reversed, and a lake formed, as we have stated in describing the course of the river Derwent. Since then this valley has been gradually drained, leaving masses of sand and gravel at various levels, till only swamps and marshes remained, which in late years have been further drained by artificial means.

* If the superficial deposits were removed the sea would again enter this valley to beyond Malton.

CHAPTER XVIII.

ECONOMIC GEOLOGY.

THE mineral resources of Yorkshire are of great variety and importance; and have been the foundation of the immense wealth of this county. It is only, however, during the present century, since the introduction of railways, that these have been made fully available; during which period there are few parts of the country that have undergone so complete a change as the great coal and iron centres of Yorkshire. Although we have now to deal with only a small portion of the county (about one sixth), we shall be able to show that this north-east part contributes a fair share of its entire wealth, and has perhaps as great a variety of minerals as the rest of the county altogether.

Before proceeding to recount the really valuable minerals we may pause to notice the list printed in that singular production the Scarborough Catalogue (1816), as it shows the great variety of mineral substances that may be found in the neighbourhood of the coast alone. A large proportion of the minerals here named occur in boulders in the Drift, and most of them only sparingly. We draw attention to this list more for the sake of its curiosity and from its showing the state of knowledge at that time, than from any real value that attaches to it.

In this list only a portion of the substances named are found in the Jurassic rocks themselves, and most of them are of little commercial importance. The really valuable minerals, which have contributed most to the advancement of the wealth of the district, are almost entirely overlooked. The principal of these is undoubtedly the ironstone.

Ironstone, its History, &c.

Iron in various states of combination, occurs throughout the Jurassic rocks, and iron-ores of more or less value are found at various horizons, but only a few of these are of sufficient importance to be utilized for commerce. For instance ironstones occur to some extent in all the following rocks, and of most of them trials have been made at one time or another; but all are now abandoned except those of the Dogger and Middle Lias.*

* Prof. Phillips, Geol. of Yorksh. Coast, 3rd Ed., p. 175, gives a more extended list than this; but these are the only beds which as far as we know have really been tried as iron ores.

Kellaways Rock -	- Upper part. Along the coast, Danby Moor, &c.
Cornbrash - -	- In Newton Dale, Rye Dale.
Upper Estuarine Series	- Irregular bands of granular ironstone. Coast, Fylingdales Moor.
Grey Limestone -	- Impure bands. Eller Beck.
Eller Beck Bed -	- Goathland, Egton Grange, Ingleby Greenhow, Snilesworth Moor.
The Dogger - -	- In the neighbourhood of Runswick, Kildale, Esk Dale, Thirsk, Farndale, Rosedale, and Kirkham.
Middle Lias -	- The numerous ironstone bands of the Cleveland district.
Lower Lias - -	- Numerous nodular bands in the upper portion.

Many of the thin, and generally very impure, beds mentioned in this list were in ancient times worked, either by the monks or the older inhabitants of these hills, in numerous shallow pits near the outcrop, as at Dry Heads, Killing Pits, Holey Intake, Danby Moor, and other places,* which have been supposed by some antiquarians to be the remains of "Ancient British Settlements."† The ironstone obtained from these shallow workings was smelted in the primitive open hearth or blomary,‡ the evidence of which remains in the heaps of scoriæ, called on the Ordnance Map "Cinder Hills," which may be seen at Julian Park near Goathland, along the valley of the Esk, at Rievaulx Abbey, and elsewhere. The following extracts from the Reports of the Board of Agriculture, 1794, p. 18, show that iron was worked in these dales at a very early period:—"Bilsdale, Brantsdale, and Rosedale, and probably some other dales, contain great quantities of ironstone, though at present no use is made of it; but the vast heaps of iron-slag and the remains of the ancient works, prove that much iron must have been made there in former times; nor are the appearances of the hearths where charcoal has been burnt everywhere scattered over these wooded dales, as well as in some places in the neighbourhood of which wood no longer remains, a less convincing proof that great quantities of charcoal have formerly been demanded in this country, which could have been applied to no other purpose; but at what time these works have been carried on, no record now remains to show."§

* Ayton Forge, near Hackness, which gives its name to this part of the Derwent valley, was worked near the commencement of the present century. See Young, Hist. of Whitby, p. 819. This forge was working in 1788. See Marshall, Rural Economy, p. 276.

† Accounts of these are given in the various Histories of the district, but they are always erroneously stated to be habitations.

‡ There is a full account of iron smelting in early times in Percy's Metallurgy (Iron and Steel), p. 873, et seq.

§ "An inspeximus, dated at York, 26th February 2nd of Edward III. (anno 1328) recites the grant of a medow in Rosedale called Baggathwaite, to the nuns of Rosedale, by Robert de Stuteville, which grant bears date at York 16th of August, 11th of John (anno 1209); a confirmation of that grant by Eustachius de Stuteville, excepta tantem modo forgea sua, and also a remission and quit claim of the same Eustachius to the said forge, ita quod eadem forgea penitus amoveatur et nullo hominum unquam reædificetur ad ipsarum monilium danaum seu nocumentum; Dug. Monast. tom. i. p. 507. Edit. 1655." Grants of ironstone were also made to the monks of Byland and Rievaulx. Ibid., p. 177, and Burton's Monasticon, pp. 332, 360, 363.

After the extinction of these primitive furnaces many centuries elapsed during which the existence of ironstone in these hills was practically forgotten, and it was not till rather more than a century ago that the attention of the ironmasters of the North was drawn to the rich store of this mineral that cropped out on the coast. In modern times the first we hear of Yorkshire ironstone is in 1745, between which year and 1748 the nodules were collected from the shore at Robin Hood's Bay and sent to the Whitehill furnaces in Durham; these furnaces were, however, abandoned before the end of the century; but ironstone was still continued to be collected from various places along the coast, and sent to the Tyne Iron Company at Newcastle.

Between 1815 and 1820 this company began to tear it up off the shore, but from the difficulty in shipping it along so exposed a coast, these works were soon given up. Previously to this ironstone had been found along the inland escarpment, although it was not put to any practical use till some time later. Thus in 1811 William Ward Jackson had samples sent from his property at Upsal to the Tyne Iron Works, but they were stated to be valueless; and in the following year Thomas Jackson opened out the full thickness of the ironstone at Lackenby, which is now part of the Eston mines. This is generally considered to be the first discovery of the Cleveland Main Seam, although no doubt its existence was known to many people previously. In 1822 Messrs. Young and Bird noticed the ironstone bands in the face of Boulby Cliff, and estimated their thickness at 15 feet. This probably included the Main and Pecten Seams, but omitted the lower beds which are here very thin.

In 1827 J. Bewick made a survey of the coast from Flamborough to the Tees for the Birtley Iron Company, and recommended Kettleness as the most advantageous place for working ironstone, but no use was made of this at the time.

In 1829 Professor Phillips made his survey of the coast; and, although he also notices the ironstone series and estimates their thickness at from 20 to 40 feet, their commercial importance does not appear to have been recognized for some time longer. In fact the neglect of ironmasters to take advantage of these discoveries has been alluded to by Professor Phillips in the last edition of the Geology of the Yorkshire Coast: "If science be to blame for not having more loudly invited attention to the unequalled store of mineral wealth existing in these hills, practice must not be exonerated from the charge of indifference to geological discoveries which had been clearly announced. Each, in fact, did its appropriate work, perhaps too exclusively; but the railway and the locomotive have brought them into harmonious co-operation in one of the grandest and most prosperous enterprises of our time."*

About this time attention was again turned to the Oolitic ironstone which had been neglected since the days of the primitive ironworks previously mentioned.

* Phillips, Geol. of the Yorksh. Coast, 3rd Ed., p. 175.

In 1829 Attwood found the Dogger, or Top Seam as it is called, near Sutton-under-Whitestonecliff, and in 1830 also near Boltby; but these discoveries have never been put to any practical use.

In 1833 Dr. Merryweather discovered ironstone (probably the Dogger) below "Godeland" church; but, although there are several levels into this bed and a tram-road was made along the side of the beck, we are not aware that it has been worked to any extent.*

In 1836 Louis Hunton gave a detailed measurement of the Ironstone Series in Rockcliff, and pointed out its characteristic fossils. In this year the Whitby Railway was opened, and attention was also drawn to the Pecten Seam at Grosmont by Messrs. H. Belcher and Wilson, which was stated to be 4½ feet thick.† The consequence of this was that the Whitby Stone Company, composed of twenty-four leading men of Whitby, including Stephenson, was started to work ironstone, whinstone, and sandstone, which was shipped to London, the Tyne, and other places; but their operations as far as the ironstone was concerned did not meet with much success, probably on account of the inferior samples sent to the Birtley and Tyne Iron Companies. In the following year, however, better samples were sent to the Tyne, which aroused the attention of the Wylam Iron Company, who despatched Bewick to again examine the Yorkshire Coast, with the result that workings were again commenced in 1838 at Kettleness and Staithes. Shipments from this exposed coast could, however, only be effected in summer time, and this caused the proprietors of the Wylam Iron Company to turn their attention to some inland locality where a constant supply could be obtained. Fixing upon Grosmont, which had lately become accessible from the completion of the railway to the port of Whitby, they commenced operations here in 1839, which have since been carried on to the present day, notwithstanding the numerous checks that have been experienced from time to time.

In this year Neasham sent a cargo collected from the outer part of the Coatham Scars to Alloa in Scotland; but it, like all the early attempts to introduce the Yorkshire ore, was rejected as valueless.

In 1842–43 the iron trade became in a most depressed condition, and the discovery of the black band in Scotland caused the Yorkshire ore to be almost if not completely abandoned. This state of things continued till 1845, when the revival of trade again brought the Cleveland stone into request; and the following year Messrs. Bolckow and Vaughan began to obtain their supplies from Grosmont for their furnaces at Witton Park.

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* Dr. Merryweather, Whitby Lit. and Phil. Soc. 1853, p. 38. Bewick, Geol. Treatise, p. 18.

† H. Belcher, Illustrations of the Scenery on the line of the Whitby and Pickering Railway. 1836.

In 1848 Messrs. Roseby commenced working the main seam at Skinningrove, but failing in their contract the works passed to Messrs. Bolckow and Vaughan. These gentlemen in 1850, experiencing the difficulty in shipment of the ore from this place, sought out and found the same ironstone in the Eston Hills, not far from their rolling mills at Middlesbrough. Although this ironstone had previously been discovered by Jackson in 1811, no use had been made of it up to this time; so that to Messrs. Bolckow and Vaughan, in great measure, is due the merit of first introducing the Cleveland stone to public notice, and of starting the vast industry which has since sprung up in this district.

It was, however, not so much the rediscovery of the thick seam at Eston, which laid the foundation of the Cleveland iron trade, as the great improvements made in its manufacture, whereby this somewhat impure ironstone was able to compete with the richer ores of Scotland and elsewhere. This was also principally due to the energy and foresight of Messrs. Bolckow and Vaughan, who recognized the importance of the Yorkshire ore, and restored the confidence of the Durham ironmasters in its value. The following account of the progress made in iron smelting, and the means adopted to effect greater economy, is given in the Geological Survey memoir on North Cleveland, from facts communicated by Mr. L. Gjers of Middlesbrough:—

"In 1851 Messrs. Bolckow and Vaughan built the first Middlesbrough furnaces, which were 42 feet high and 15 feet diameter in the bosh, having a capacity of 4,566 cubic feet. They seem to have recognised the great principle that more work could be got out of the furnaces by making them larger, and accordingly, in 1856, they built two furnaces 55 feet high and 16 feet in the bosh, having a capacity of 7,175 feet. In these at first 40 cwt. of coke was required to produce a ton of iron, and the out-put of each was 100 tons a week; but by carefully-conducted experiments they managed to reduce the amount of coke tc 35 cwt. and to increase the out-put to 150 tons per week, which at that date was considered a very extraordinary performance.

"At this time the furnaces were all open at the top, and the appearance of the country at night gave one the impression of pandæmonium. But in 1856 Bolckow and Vaughan made the first experiments with furnaces with closed tops, and had at the outset much prejudice and many difficulties to encounter. But by the year 1860 they brought the process to a complete success, and the old system was abandoned. The effect of closing the top was to enable them to utilise the whole of the escaping gases, which hitherto were wasted. These gases were conveyed by a huge pipe from the top of the furnace to the boilers and hot-blast stoves, where they were burnt in place of the fuel formerly used. This at once effected a saving of from 10 to 12 cwt. of coal for

each ton of pig-iron; besides dispensing with all the labour of stoking. In addition it was found that it required an average of 10 cwt. less of coke for each ton of metal.

"Before the introduction of closed furnaces it required 50 cwt. of ironstone, 35–40 cwt. of coke, and 12 cwt. of limestone to be used inside the furnace to yield one ton of iron; but as soon as the closed furnaces were got into working order the same yield was obtained from about 25 cwt. of coke with the former quantities of ironstone and limestone.

"A great improvement was at the same time effected by raising the temperature of the hot blast. Previous to 1856 this was about 650° Fahr. or 'lead heat'; it was now raised to about 1000° where iron pipes were employed; while in the fire-brick stoves it has been brought up to as much as 1300° or 1400° Fahr.

"Experiments were also tried with enlarged furnaces, the results of Bolckow and Vaughan's early efforts seeming to point to the possibility of great saving in this direction. What has been done is clearly shown by the following table, giving the dimensions of the best known furnaces in different years:—

Year.	Height.	Diameter in Bosh.
	Ft.	Ft. In.
1851	42	15 0
1858	61	16 4
1861	60	20 0
1862	75	16 6
1865	81	19 6
1866	95	16 0
1870	85	25 0

"The last may be taken as a fair average of the present dimensions of the Middlesbrough furnaces. They have been built as large as 96 feet in height and 30 feet in the bosh, and have yielded good results—indeed, one is 105 feet high—but there seems no doubt that this has passed the point of economy.

"When in good working order an average furnace requires about 20 cwt. of coke, 48 to 50 cwt. of calcined ironstone, and 12 cwt. of limestone to produce a ton of pig-iron. The limestone is not usually calcined. The amount of hot air required to be driven through the furnace is roughly 140,000 cubic feet. Under these conditions a good furnace will yield about 500 tons of iron per week. They have been made to yield 600 and 700; but this is by increasing the pressure of the blast, technically known as 'hard-driving.' It tends to wear the lining of the furnaces very rapidly, and can only be remunerative when profits are high, a state of things that has not been known in this country for many years.

"The raw ironstone is calcined in large cast-iron kilns, to drive off the water and combined carbonic acid. This causes an increase in the per-centage in the ore from about 30 to about 40 per cent. Originally the stone was calcined in heaps; but this, in addition to being a very dirty method, was very wasteful of fuel; kilns were therefore gradually introduced. These were at first of brick or stone, with thick walls, but now the Gjers-kiln is the form usually adopted. This consists of a wrought-iron shell, lined with fire-brick, in shape like a cylinder with a truncated conical base, supported on cast-iron pillars 2 feet 3 inches high. This enables the barrows to be put under the bottom, which has a sliding door, and the former can be easily filed in a few seconds. The kilns are being constantly filled with ironstone and fuel, and the former is calcined in its passage downwards. One ton of small coal is required to calcine about 25 to 30 cwt. of ore. The average size of the kilns is from 30 to 40 feet in height by 24 feet diameter, and one of them is capable of calcining from 800 to 1,000 tons of raw stone per week.

"The increased height of the furnaces has been accompanied by an increase in the pressure of the blast from the original average of 3 lbs. to the inch to 5 or 6 lbs. In some cases a greater pressure than this is used, but the advantage of it is a matter of dispute.

"When Messrs. Bolckow and Vaughan first began their experiments, in order to obtain one ton of pig-iron some 50 cwt. of coke were used in the furnace, and about 10 cwt. of coal in the generation of steam and the hot-blast; while the whole work is now done by 20 cwt. of coke. This means that under the new order of things the Durham Coal-Field can be made to smelt about three times the amount of iron that it could have done under the old plan."

The rapid growth of the Cleveland iron trade from its first commencement at Middlesbrough in 1850, is one of the most wonderful examples of the power of industry in modern times, and is almost without parallel in the commercial history of the kingdom. In the first 10 years, that is by 1860, the annual amount of pig-iron made from the Yorkshire stone rose from a mere nominal amount to about 250,000 tons, employing a capital of from two to three millions sterling. This great industry so well begun has continued to thrive; and, although it may in recent years have somewhat declined from its greatest prosperity, it still maintains its position among those other industrial communities, which have contributed so much to the wealth and prosperity of the British Empire.* The following table of statistics will help to give some idea of the rapid progress of this trade, and of the gradual decline since it reached the summit of its prosperity.

* Meade in 1874 stated that the production of Cleveland was equal to 36 per cent. of the United Kingdom.

Year.	Tons raised.	Average Price per Ton.	Value of Ore.	Make of Pig Iron.	No. of Furnaces. Built.	No. of Furnaces. In blast.	Average per Furnace.
	Tons.	s. d.	£	Tons.			Tons.
1854	650,000	—	—	—	—	—	—
1855	—	—	—	84,500	23	21	4,024
1856	—	—	—	—	—	—	—
1857	1,414,155	—	—	—	—	—	—
1858	1,367,395	—	—	—	—	—	—
1859	1,520,372	—	—	—	—	—	—
1860	1,471,319	6 0	—	248,665	33	25	9,946
1861	1,242,514	—	—	—	—	—	—
1862	1,689,966	—	—	—	—	—	—
1863	2,078,806	—	—	—	—	—	—
1864	2,401,890	—	—	—	—	—	—
1865	2,762,359	—	—	486,421	65	53⅓	9,011
1866	2,809,061	—	—	—	—	—	—
1867	2,739,039	—	—	—	—	—	—
1868	2,785,307	—	—	1,233,418	—	—	—
1869	3,094,678	—	—	1,459,508	—	—	—
1870	4,072,888	5 0	—	1,695,377	74	67	13,686
1871	4,581,901	5 0	1,144,974	1,884,239	—	—	—
1872	4,974,950	7 6	1,863,081	1,968,972	—	—	—
1873	5,617,013	—	1,688,099	—	—	—	—
1874	5,614,322	6 0	1,694,918	—	—	—	—
1875	6,121,794	4 0	1,222,358	1,240,243	87	73	16,990
1876	6,562,000	3/4—3/9	1,162,020	—	—	—	—
1877	6,284,545	3/0—3/6	1,021,238	—	—	—	—
1878	5,605,640		910,739	—	—	—	—
1879	4,750,000	2/9—3/3	712,500	—	—	—	—
1880	6,486,655	3/3—3/9	1,135,164	1,666,156	91	72	23,141
1881	6,538,471	—	1,062,501	—	—	—	—
1882	6,326,314	—	1,067,566	—	—	—	—
1883	6,756,055	3 3	1,097,858	—	—	—	—
1884	6,052,608	3 3	983,549	—	—	—	—
1885	5,932,244	—	963,989	—	—	—	—
1886	5,370,279	2 9	751,103	—	92	66⅓	—
1887	4,980,421	2 11	726,311	1,181,444	91	67¾	—
1888	5,395,942	2 11	786,908	1,856,274	91	67¼	—
1889	5,657,118	3 3	919,282	1,915,050	91	69⅛	—

The marked increase of production about the year 1880 was connected with the introduction of the Thomas-Gilchrist process for the dephosphorization of pig-iron. In the old Bessemer process of steel-manufacture, it was necessary to work on pig-iron free from phosphorus, since this element was not eliminated during the conversion into steel. Neither was the phosphorus removed in the Siemens process of steel-making. Hence the Cleveland ores, being comparatively rich in phosphorus, were practically useless for the production of pig-metal to be transformed into steel.

It was shown, however, by the late Mr. Gilchrist Thomas, and his cousin Mr. Sidney Gilchrist, that it was practically possible to dephosphorize the metal if the Bessemer converter had a *basic* instead of an *acid* lining. In the original Bessemer process the vessel was lined with ganister or some other refractory material of

a siliceous character. In the basic process the lining is usually made of calcined dolomite, mixed with tar, and moulded under great pressure into bricks. The magnesian limestone of Durham yields an excellent raw material. Well-burnt lime, to the extent of from 15 to 18 per cent., is also added to the charge in the converter. Under these circumstances, a basic slag is obtained, containing practically all the phosphorus which existed in the pig-metal. So far from the presence of phosphorus being prejudicial, it appears to assist the process by means of the heat evolved during its oxidation. The introduction of the basic process naturally gave an enormous impetus to the steel manufacture of Cleveland.

It is found that the phosphorus exists in the basic slag in the form of a tetra-basic phosphate of lime, which, unlike the ordinary tribasic phosphate, is soluble in water, and therefore requires merely to be finely ground in order to be used as a fertilizing agent. In 1889 about 600,000 tons of basic slag were thus utilized in this country, the slag selling at the works for from 20*s*. to 30*s*. per ton.

We will now proceed to give a short account of the principal seams of ironstone. The stratigraphical details of these beds having been given at some length in the early part of the Memoir, it will here be only necessary to state the leading facts connected with the workable seams.*

Avicula Seam or Low Bed.—This is the lowest seam of ironstone that has been worked. It has only been used at Grosmont, where it is from 2 feet to 3 feet 9 inches in thickness, but this greater thickness does not appear to extend any distance. At Staithes it is only 1 foot 6 inches thick, so that its average thickness throughout the district may be taken as about 2 feet, which usually yields about 27 per cent. of iron. This seam is generally a rather shelly ironstone, characterized by the abundance of *Avicula cygnipes,* from which it obtains its name. Bewick, alluding to this ironstone at Grosmont, says it "is divided into four distinct strata by horizontal partings, one of which is a complete concretion of shells."†

The Two-Foot Band.—About 25 feet above the Avicula seam the Two-Foot band occurs; which, over a large area, is remarkable for its uniform thickness. About Normanby and Brotton the quality of this bed is nearly equal to that of the Main Seam, but it has not as yet been put to much commercial use, although it was at one time worked in the Ingleby Mines. At Grosmont it is only 10 inches thick, but increases towards the north-west to its titular 2 feet or more; the distance between this and the Pecten Seam above also varies, as will be seen from the following table:—

* Much of this is taken from Mr. Barrow's account.
† Geological Treatise on Cleveland, p. 46.

—	Thickness.		Depth below the Pecten Seam.	
	FT.	IN.	FT.	IN.
Upleatham - - - - - -	2	2	5	0
Longacres - - - - -	2	6	7	0
Lingdale - - - - - -	2	0	6	0
Spa Wood near Guisbrough - - - -	2	6	5	0
Hutton - - - - - -	2	7	2	8
Kildale - - - - - -	2	5	2	2
Grinkle - - - -	1	3	4	3
Staithes - - - - - -	1	9	2	7

The Pecten Seam.—This seam obtains its name from its characteristic fossil *Pecten æquivalvis*, which occurs abundantly wherever this band has been recognised. Its thickness varies from about 3 feet at Grosmont to 4 feet 6 inches at Eston; it is in most cases of poor quality, yielding about 27 per cent. of iron. It is usually split up by numerous shaly bands, and being very shelly easily falls to pieces on exposure to the air.

The Main Seam.—This, when best developed, is fairly uniform in character, consisting of a mass of bluish-green ironstone, which on exposure to the atmosphere readily weathers to a reddish brown. It is composed mainly of carbonate of iron, which by exposure to air and moisture is converted into peroxide. Dick gives the following description of the Main Seam*:—

"Chiefly a carbonate of protoxide of iron; lustre, earthy; colour, greenish gray; streak, similar; fracture, uneven, showing here and there small cavities, some of which are filled with carbonate of lime. Throughout the ore are diffused a multitude of small oolitic concretions, together with small pieces of an earthy substance resembling the ore, but lighter in colour. When a mass of this ore is digested in hydrochloric acid till all carbonates and soluble silicates are dissolved, there remains a residue having the form of the original mass of ore. It is extremely light, and falls to powder unless very carefully handled. It contains the oolitic concretions, or else skeletons of them, which dissolve completely in dilute caustic potash, showing them to be silica in a soluble state. Under the microscope, some of them are seen to have a central nucleus of dark colour and irregular shape, but none of them present any indication of organic structure or radiated crystallization. If the residue, after having been digested in caustic potash, be washed by decantation, there remains a small number of microscopic crystals; some of these, which are

* Memoirs of the Geological Survey. "Iron Ores of Great Britain," Pt. 1. page 97, 1856; and Quart. Journ. Geol. Soc., vol. xii., p. 357. Hudleston gives a microscopic section of this and the Magnetic Iron-ore from Rosedale, in Proc. Geol. Assoc., vol. xi., 1889.

ANALYSES of CLEVELAND IRONSTONE exclusive of the MAIN SEAM.

—	Avicula Seam.	Pecten Seam.	Dogger or Top Seam.						Eller Beck Bed.		
	Grosmont.	Grosmont.	Rosedale Wyke.	Raithwaite Gill.	Grosmont.	Sherrifs Drift, Rosedale.	Rosedale.	Rosedale (Magnetic).	Grosmont.	Wintergill.	Ingleby.
		Mixture of 4.	Average of 2.	Average of 12.	Average of 3.	Average of 5 samples.	Magnetic Ore.	Average of a number.	Average of 2.	Magnetic Ore.	
Analyser	Tookey.	Crowder.	Crowder.		Tookey.	Crowder.	Pattinson.	—	Supplied by Mr. Bagnall.	Morgan.	Pattinson.
Protoxide of iron	33·17	35·55	—	—	31·95	2·50	33·85	25·92	35·74	—	41·14
Peroxide of iron	—	1·80	46·25	—	—	51·50	32·67	33·56	·27	—	7·07
Protoxide of manganese	0·50	--	—	—	·54	—	0·69	0·22	·12	—	·94
Alumina	8·92	12·30	6·50	—	1·53	14·50	3·15	7·13	1·44	4·96	4·71
Lime	11·90	5·35	4·00	—	7·44	1·95	2·86	2·84	2·05	3·21	3·32
Magnesia	4·52	2·10	1·36	—	4·62	1·15	1·59	1·82	2·59	1·60	3·34
Potash	—	—	-	—	—	—	trace	—	—	—	·20
Carbonic acid	28·00	27·00	—	—	27·44	1·70	10·36	9·38	Organic matter included 22·85	—	26·00
Silica	Ignited insoluble residue 13·22 Silica 9·42	15·00	20·32	34·25	Ignited insoluble residue 22·47 Silica 16·67	12·20	Silicic acid 6·95	7·03	Ignited insoluble residue 29·05 Silica 26·20	11·06	7·37
Sulphur	—	—	—	—	—	trace	0·03	0·02	·27	·33	·08
Sulphuric acid	—	—	—	—	—	trace	trace	—	trace	—	—
Phosphoric acid	0·48	—	—	—	·18	—	1·41	1·57	·96	1·68	1·36
Organic matter	–	—	—	—	—	—	0·84	0·56	—	—	·38
Water	3·65	2·30	—	—	2·90	11·50	3·76	11·06	2·20	—	3·86
Total	99·36	—	...	-·	—	97·00	98·16	—	97·91	—	99·77
Metallic iron	25·80	28·51	32·37	31·06	24·85	38·01	49·17	42·95	27·96	36·78	36·95

white, are quartz, and others, which are black, and acutely pyramidal, consist chiefly of titanic acid."*

This seam, which is the most important of all the ironstones, has a thickness of 11 feet at Eston, where it rests directly on the Pecten Seam, and the two are mined together, giving the immense thickness of 15 feet 6 inches of workable ironstone. But as we have mentioned before, the beds soon become separated by a band of shale, and its thickness decreases in a south-east direction, so that by the time we reach the valley of the Esk it is scarcely recognizable.†

As will be seen from the table of analyses on pp. 445-6, which have been compiled from the publications of Crowder, Percy, Bell, and the Geological Survey, the constituents of the ironstone vary considerably, not only in different localities, but also in different parts of the same seam.‡

AVERAGE of the most important INGREDIENTS of the IRONSTONE SEAMS.

		Main Seam.					Pecten Seam.	Dogger.					
—		Skelton.	Upleatham.	Eston.	Normanby.	Hutton.	Grosmont.	Raithwaite.	Rosedale Wyke.	Grosmont.	Rosedale (Sherriffs Drift).	Rosedale (Magnetic).	Eller Beck Bed.
Phosphoric acid -	-	2·36	1·28	2·39	1·55	2·21	—	—	—	·18	—	—	1·24
Silica - -	-	9·10	13·42	11·98	12·80	13·86	15·10	34·25	20·32	16·67	11·84	7·66	17·55
Metallic iron -	-	34·94	31·85	31·27	30·62	30·09	28·60	31·06	32·37	24·85	37·56	43·14	32·41
Phosphoric acid -	Maximum	—	2·70	3·87	—	5·05	—	—	—	0·30	—	—	1·74
	Minimum -	—	0·45	1·02	--	0·67	—	—	—	0·06	—	—	·19
Silica -	Maximum	—	20·50	19·95	—	20·90	17·00	68·85	30·35	23·10	15·00	8·90	30·07
	Minimum -	—	7·45	6·00	—	7·20	12·20	12·45	10·30	8·80	8·70	6·20	7·37
Metallic iron -	Maximum	—	34·30	35·10	—	34·75	31·85	45·25	36·82	31·71	39·93	49·78	36·96
	Minimum -	—	28·42	21·10	—	26·29	25·23	16·69	27·93	17·34	35·10	34·75	30·53

The diagram on page 447 shows the variation in the main constituents of the principal seams.

* "Professor Miller, of Cambridge, succeeded in measuring some of the angles of the crystals containing titanic acid, and found that they correspond to similar angles in anatase. The green colour of the ore seems to be due to a silicate containing peroxide and protoxide of iron, but this could not be exactly determined, because it was not found possible to dissolve out the carbonates without acting at the same time upon the silicate of iron."

† According to Mr. Barrow all the good stone lies north of a line running from Spa Wood near Guisbrough, to the north side of South Skelton Shaft, and thence to Hummersea on the coast, a little more than a mile east of Skinningrove Beck.

‡ W. Crowder, Edinb. New Phil. Journ., ser. 2 vol. iii., p. 286, 1856; and vol. v., p. 35, 1857. Dr. Percy, Metallurgy (Iron and Steel), p. 221, 1864. I. L. Bell, Brit. Assoc. Reports for 1863, pp. 745, 755.

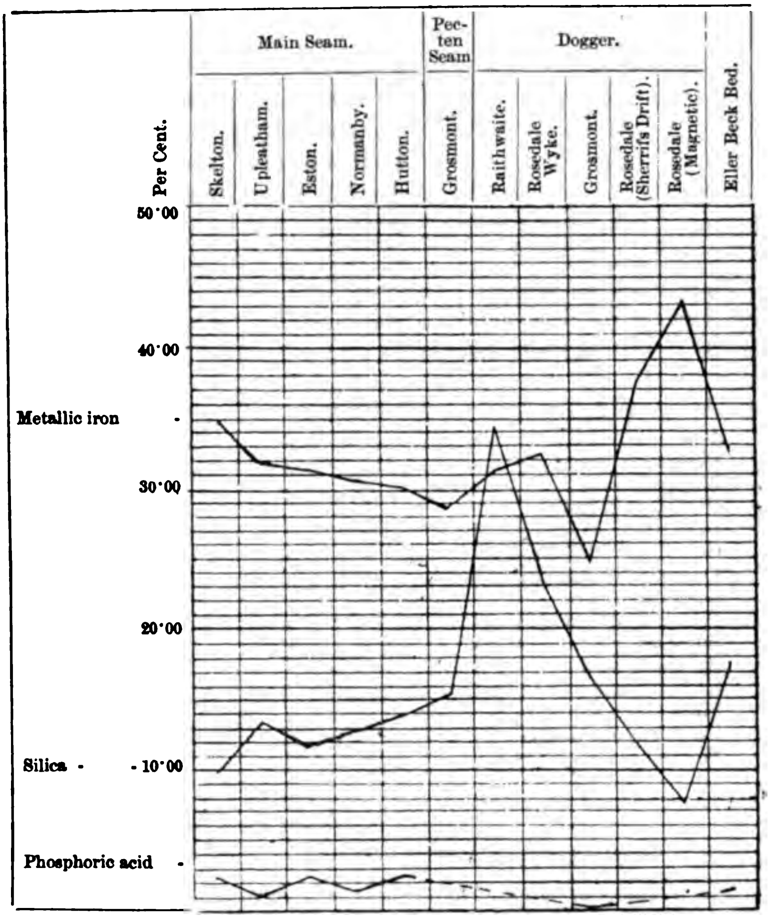
	Normanby.				Hutton Low Cross.					
	Bottom 8 Feet.	Top 3 Feet.	Bottom 8 Feet.*	Sulphur Band.	1.	2.	3.	4.	5.	6.
	.	Pattinson.			Crowder.					
Protoxide of iron	05	33·86	38·06	9·97	35·55	40·36	37·41	35·75	38·39	40·86
Peroxide of iron	69	0·47	2·60	—	1·70	2·41	—	1·80	5·16	4·25
Protoxide of mang	—	0·96	0·74	—	—	—	—	—	—	—
Alumina	41	6·92	5·92	8·47	3·79	3·71	9·86	4·95	3·79	3·44
Lime	35	5·82	7·77	·49	4·20	2·70	3·08	7·39	3·00	3·80
Magnesia	39	3·84	4·16	1·07	1·12	0·49	trace	2·98	4·80	3·70
Potash	—	—	—	—	—	—	—	—	—	—
Carbonic acid	29	25·00	22·00	—	25·18	32·72	26·32	23·47	28·40	32·50
Silica	05	15·24	10·36	10·94	20·00	12·80	16 55	15·65	13·00	7·20
Sulphur	—	0·40	0·14	Sulphur 28·37 Iron 24·82	trace	trace	trace	trace	0·05	1·60
Sulphuric acid	—	trace	trace	—	trace	0·31	trace	0·07	0·02	0·30
Phosphoric acid	66	1·40	·07	—	2·66	1·92	0·67	5·05	2·01	0·96
Water	37	3·69	4·45	13·20	4·90	2·58	6·11	4·89	1·45	1·45
Total	16	97·60	97·27	97·33	100·	100·	100·	100·	100·07	100·06
Metallic ir	96	26·66	31·42	—	28·84	33·46	29·10	27·45	33·46	34·75

* These are the a

† Crowder also gi re also given by R. Meade The Coal and Iron Industries of the United Kingdom, 1882, pp.

FIG. 24.

Diagram of the average per-centage of the principal ingredients of the Ironstone Seams.



From the foregoing analyses it will be seen that a certain amount of phosphorus is present in the ironstone. As the quality of the iron is much impaired by this substance, it is a matter of considerable importance to the ironmaster to ascertain the quantity of phosphorous contained in the different beds of ironstone. Mr. Stead, who gives the following additional analyses, showing the per-centage in different parts of the Cleveland Seam, observes that "no part of the stone is free from phosphoric acid; near the top it is highest, and in the most porous part, about 3 feet above the 'Black Hard' bed, it is very much lower;"* he states that the phosphorus is in combination with lime and not with iron; but he considers it doubtful if it comes from the fossils, as they contain less than the ironstone.

* Chem. News, 1878, vol. xxxviii., p. 15.

	Main Seam, 9 feet.									Black Hard, 21 inches.		
	1st foot.	2nd foot.	3rd foot.	4th foot.	5th foot.	6th foot.	7th foot.	8th foot.	9th foot.	7 in.	7 in.	7 in.
Iron	26·53	29·54	29·14	28·41	29·97	30·42	29·70	29·85	30·30	30·56	27·87	27·[illegible]
Siliceous matter	18·30	10·90	10·68	11·98	9·00	8·82	9·00	9·29	12·01	12·90	22·20	24·70
Phosphoric acid	1·46	1·13	1·13	1·41	1·17	0·89	0·80	0·91	1·16	0·44	1·12	0·81
Moisture	8·50	9·10	9·50	9·80	10·00	10·00	10·10	9·80	9·00	8·50	5·50	5·[illegible]
Loss by calcination	27·39	29·80	29·80	28·80	30·83	31·51	31·78	30·90	28·50	26·80	18·00	17·[illegible]
Iron in calcined stone	36·50	42·08	41·50	39·92	43·31	44·40	43·53	43·20	42·40	41·75	34·00	[illegible]

The largest amount of phosphoric acid, however, appears to be found in the fossil wood which occurs in the ironstone, as is shown by the following analysis:—

Analysis of fossilized wood found in the Cleveland Ironstone.

Lime	27·60
Phosphoric acid	20·80
Magnesia	1·12
Protoxide of iron	10·02
Iron	5·20
Cobalt and nickel	1·65
Oxides of cobalt and nickel	3·70
Alumina	8·25
Protoxide of manganese	trace
Sulphur	7·56
Sulphuric acid	0·60
Carbonic acid	0·75
Silica	0·50
Carbonaceous matter	9·60
Water	3·00
	100·35
Lime Phosphate	45·41

Other samples gave phosphate of lime 16·0, 23·1, 27·8 respectively.

The Dogger or Top Seam.—The Top Seam,* as it is called by the miners, is the lowest of the Oolitic ores, occurring at the base of that formation. As we have shown before this bed is very variable in character, being generally a sandstone, but sometimes an ironstone, and more rarely a limestone. The thickness of the stone, where it has been worked, usually varies from about 1 to 4 feet, but increases in Rosedale to as much as 14 feet; where the magnetic ore, which also occupies the same horizon, has the enormous thickness of 70 feet.

The Dogger itself apparently overlies the magnetic ore, and there is said to be a line of waterworn pebbles along the junction. The greater part of the magnetic ore, as we have noticed in the

* This name appears to have been given by Bewick, who erroneously maintained that it was part of the Lias; and who objecting to its being classed with the Inferior Oolite by Prof. Phillips and other geologists, makes the following observation. "Believing it, however, to belong to the period of the deposition of the Lias, we ventured, some time ago, to designate it 'the top seam of the Lias formation.'" Geological Treatise on Cleveland, p. 54.

stratigraphical description of these beds, occurs in two trough-shaped masses about 70 feet thick. It is composed of a confused mass of irregular lumps 3 to 4 feet in diameter; these usually consist towards the interior of dark blue compact oolitic ironstone, with a skin or crust of paler and dark brown purplish layers of sandy or solid ironstone. It does not appear to contain any organic remains, probably because the iron is in the state of peroxide.

The Rosedale mines where this ore has been principally worked were first started shortly after 1858,* in which year a trial boring was made by the Rosedale Iron Company, and the following year Messrs. Leeman and Partners obtained the lease for 60 years of 8,000 acres in West Rosedale and Spaunton. In 1860–61 the branch railway was made across the moors from Ingleby for the transit of the ironstone to the furnaces at Ferryhill. About 1874 this firm became associated with J. Morrison of Newcastle under the style of The Rosedale and Ferryhill Iron Company, and having purchased the Rosedale Abbey Estate opened up the east side of the dale, and the workings were further increased by sinking the Sherrifs Pit. In 1879 the mines were stopped owing to the depression in trade, but the following year Sherrifs Pit and West Rosedale Mines were bought by the West Rosedale Ironstone Company, and a small output of the magnetic ore was carried on for a time. In 1873 Messrs. Navery and Company opened the Farndale Mines, but they were not long in operation.† The following is the amount of ironstone obtained from the Rosedale Mines up to 1881 :—

Year.	Tons.	——		
1861	79,786	Magnetic ore.		
1862	219,123	,,		
1863	224,889	,,		
1864	297,579	,,		
1865	250,000	,,		
1866	233,382	,,	and East mines.	
1867	178,227	,,	,,	
1868	210,082	,,	,,	
1869	269,595	,,	,,	
1870	317,060	,,	,,	
1871	314,394	,,	,,	
1872	450,350	,,	,,	
1873	560,668	,,	,,	
1874	473,140	,,	,,	
1875	383,914	,,	,,	and Sherrifs Pit.
1876	383,828	,,	,,	,,
1877	347,486	,,	,,	
1878	234,150	,,	,,	
1879	25,593	,,	,,	(Mines closed in March.)
1880	Nil.	,,	,,	
1881	6.079	,,	,,	(Sherrifs Pit re-opened.)
	5,459,325			

* The ironstone was noticed by W. Thompson in 1851. Marley, Trans. N. Engl. Inst. Eng., vol. v., p. 207.

† The above particulars and the accompanying table are taken from the paper by C. Parkin "On the Mineral Resources of the Rosedale Abbey District." Trans. N. Engl. Inst. Eng., vol. xxxii., p. 48.

In the East Mines previous to 1879 about 130 acres had been worked out.

This ironstone, excepting the magnetic ore, is very inferior to that obtained from the Middle Lias; the rock usually consists of a coarse siliceous sandstone containing only from 15 to 20 per cent of iron, but it is sometimes more oolitic, and then it forms a much richer ore containing as much as from 30 to 35 per cent. of iron. The rock has been tried as an ironstone at the following places:—Raithwaite Gill near Whitby, Rosedale Wyke near Runswick, Grosmont, Glaisdale, Eskdale, Rosedale, Kildale, Ingleby, and various other places along the western escarpment as well as at Kirkham in the Howardian Hills.

*The Eller Beck Bed.**—This is the only other bed that has in modern times been tried as an ironstone. The per-centage of iron in this rock is, however, so variable that in only a few places is it likely to be of any value. In former ages this rock was one of the principal sources of iron, and it has been tested in modern times in the neighbourhood of Grosmont, at Wintergill, where a portion of the ironstone is magnetic, at Ingleby Greenhow and on Snilesworth Moors. At Ingleby Greenhow this ironstone is said to have contained over 40 per cent. of iron, and, as will be seen from the subjoined analyses, it is also occasionally very rich in other places, but its character is so inconstant that it is not worth the expense of working at the present time.

Analyses of the Eller Beck Ironstone.†

	No. 1.	No. 2.
Protoxide of iron	38·87	32·62
Peroxide of iron	·41	·13
Protoxide of manganese	·08	·16
Alumina	·89	1·99
Lime	2·40	1·70
Magnesia	2·63	2·56
Sulphur	·35	·19
Sulphuric acid	trace.	trace.
Phosphoric acid	·19	1·74
Carbonic acid and organic matter	25·17	20·53
Total water	2·30	2·10
Ignited insoluble residue	24·40	33·70
	98·41	97·42
Silica in insoluble residue	21·70	30·70
Alumina with a little lime and magnesia	2·70	3·00
Iron in raw sample	30·52	25·40
Lost by calcination	23·50	19·20
Iron in calcined stone	39·89	31·51

* This bed was called by Marley "the Ingleby Top or Third seam." Trans. N. Eng. Inst. Eng., vol. v., p. 202.

† Furnished by Mr. Bagnall, of Grosmont. No. 1 is the upper bed and No. 2 the lower bed of ironstone in the first section given on page 197.

*Analysis of the Eller Beck Ironstone (magnetic ore) from Wintergill.**

Iron	36·78
Silica	11·06
Alumina	4·96
Phosphoric acid	1·68
Lime	3·21
Magnesia	1·60
Sulphur	·33
Iron in calcined stone	47·00
Loss by calcination	22·78

Several estimates have been made of the amount of workable ironstone contained in the Jurassic rocks of Yorkshire, and of the probable time this quantity may be expected to last at the present rate of consumption. In a calculation of this sort so many errors are liable to creep in that the result can only be accepted as roughly approximate. The following table has been drawn up from the results obtained by Mr. Barrow.†

Amount of workable Mineral contained in the Ironstone Seams.

		Estimated total Amount.	Yearly Output.	Total Amount used up to 1880.	Amount left allowing about one tenth for loss in working.	At the rate of consumption in 1880 mine estimated to last until
Main Seam.	Eston royalty	86,640,000	800,000	16,000,000	60,000,000	1950
	Normanby royalty	8,300,000	225,000	5,000,000	2,500,000	1885
	Ormesby "	2,600,000	75,000	500,000	1,800,000	1895
	Dunsdale "	3,250,000				
	Upleatham district	36,100,000	700,000	Above 12,000,000		1905–1910
	Skelton and Huntcliff district.	173,280,000	1,800,000	24,190,000	145,000,000	1940–1960
	District 13 miles by 2½ south of the above where the ironstone is poorer.	375,480,000				
Pecten Seam		400,000,000				
Two-Foot Seam		380,000,000				

Avicula Seam covers over 100 sq. miles.
Dogger.
Eller Beck Bed.
} These beds are too variable and at present too little worked to form an estimate of the amount of ironstone they contain

These results differ very largely from those obtained by Bewick, who, basing his calculations upon the amount obtained from the Pecten and Avicula Seams at Grosmont, which he believed to be the equivalent of the Cleveland Main Seam, and which are together over 5 feet thick, estimated that the entire quantity obtainable was equal to 4,820,659,200 tons. Of this large amount he estimated that 7,000,000 tons were consumed per annum, so that the whole supply would last 680 years! There is no doubt that this estimate is a gross exaggeration of the amount actually available. It seems to us that the principal cause of error arises

* By W. Morgan.
† Proc. Cleveland, Inst. Eng., 1879–80, pp. 108, 180.

from the large area (30 miles by 16) assumed to contain workable ironstone, and also from an exceptional thickness (over 5 feet) being taken as the average development of ironstone over this area.

Steavenson estimated the area that could be worked at a profit as between 50 and 60 square miles (about 35,000 acres).* Meade on the other hand considered that there were not more than about 16,000 acres untouched, which allowing a consumption of about 150 acres per annum would last rather more than 100 years.† This latter estimate agrees very nearly with that given by Barrow.

Alum.

The manufacture of alum from the shales of the Upper Lias was, in former years, one of the principal industries of this district; but the discovery of a cheaper means of making it from the shales of the Coal Measures has caused these works to be entirely abandoned. During the height of their prosperity the alum works brought in considerable sums of money, but the large profits made soon led to competition, which so overstocked the market that many of the works had to be closed. It however still formed the staple trade of the district, until it was transferred to the great Coal Fields, where the cheapness of fuel and facilities of carriage for the manufactured product, placed the works of this district at a great disadvantage, and they were discontinued. The manufacture of alum is now chiefly carried on in the neighbourhood of Manchester, where Mr Spence has a manufactory of ammonia-alum producing 150 tons a week. His method, which is also carried on at Goole, was patented about the year 1860, and consists in treating the carbonaceous shales of the Coal Measures with sulphuric acid.‡

There is no doubt that the working of the Lias shales for the manufacture of alum has been carried on from a very remote period. Young, in his History of Whitby, gives the plan of an old alum working at Grosmont in a field called The Alum Garth;§ which he considers may have been founded by the Romans or by the monks, although there is no history or even tradition concerning it. The first authentic record we have of alum works being established in England was towards the end of the reign of Queen Elizabeth;|| when Sir T. Chaloner, having tasted the water

* Steavenson, Journ. Iron and Steel Inst. 1874, p. 336.

† Meade, The Coal and Iron Industries of the United Kingdom, 1882, p. 380.

‡ In 1870 Mr. Spence patented a process for using phosphate of alumina and iron, obtained from the island of Redonda near Antigua.

§ Young's History of Whitby, p. 759.

|| The date is given as 1460 in the report "On the Chemical Manufactures of the Northern Districts." Brit. Assoc. Rep. for 1863, p. 709. But this must be an error. There seems to be much uncertainty as to the exact date when alum was first manufactured in this country. In Ord's History of Cleveland, p. 80, it is stated that Dr. Fuller, in the "Worthies of England," who wrote about sixty years after the introduction of alum, does not mention Sir T. Chaloner, but the workmen are said to have been brought from Rochelle.

issuing from these shales and found it similar to what he had seen in Germany, brought over some men from the Pope's factories in Italy, which until then had had a monopoly of the trade, and started an alum work at Guisbrough.* In 1608 the manufacture was improved by Sir J. Bouchier, who is stated by some authorities to have introduced the art. During the Pope's monopoly of this trade the price of alum is stated to have been as much as 53*l.* a ton, but upon its introduction into England the price fell to 20*l.* Owing however to ignorance and bad management the manufacture was carried on at a loss until the reign of James I. when a monopoly was created for the English makers; the works were decreed to be a royal mine, and passed into the possession of the Crown. They were afterwards farmed to Sir Paul Pinder, at a rental of 15,000*l.* per annum. He employed about 800 persons, and made large profits, his monopoly enabling him to keep up the price to 26*l.* per ton. When the monopoly ceased at the end of the reign of Charles I., the manufacture enormously increased, and the market became so overstocked that in 1736 the price fell to 10*l.* After this the price of alum was subject to considerable fluctuations, but the trade was never so prosperous as in 1769, when no less than sixteen works were going at the same time. From 600 to 800 men were employed in these works; and, during the progress of their greatest prosperity, no less than from 5,000 to 6,000 tons of alum were produced annually.

Previous to the establishment of the alum industry Whitby was only a small fishing village, but the necessity of procuring coal for these works induced the inhabitants, about 1650, to send ships to Newcastle, and other places for coal; and afterwards to build ships of their own, so that in course of time the town became an important maritime port.

The following list of alum works, with the dates when they are supposed to have been opened or closed, is taken from Charlton's and Young's Histories of Whitby, with a few additions from other sources.

Belman Bank near Guisbrough, opened 1595, closed about 1620; re-opened 1766, closed about 1800.
Spa Wood and Rock Hole near Guisbrough, opened 1600, closed between 1615 and 1620.
Sandsend, opened 1615, closed in recent years.
Old Peak.
Boulby, closed since 1861.
Lofthouse (Lingberry) closed since 1863.
Peak, closed since 1817.
Saltwick, opened 1649, closed 1708; re-opened 1755, closed 1791.
Little Beck, opened 1660, closed 1809.
Carlton, opened 1680, closed about 1774.
Holmes near Mulgrave Castle, opened 1680.

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* For thus destroying the monopoly of the Pope, Sir T. Chaloner and his workmen were excommunicated. A full account of this is given in Charlton's History of Whitby, p. 306, and in Young's History of Whitby, p. 808.

Ash Holme near Old Mulgrave Castle.
Rock Hole „ „ „ „
Hagg, near Saltburn, opened 1680, closed 1720; re-opened 1765, closed 1776.
Kirkby-in-Cleveland.
Kettleness, opened 1728, closed before 1736; re-opened 1742, closed 1754; re-opened 1767, closed since 1861.
Osmotherley, opened 1752, closed 1772.
Stoupe Brow, opened 1752, closed since 1817.
Eskdale Side, opened 1764 „ „ „
Godeland Banks, opened 1765, closed 1805.
Ayton, opened 1765, closed 1771.

All the above alum works are situated either on the edge of the cliff, on one of the great escarpments, or in the gorge formed by some stream in the Alum Shales; in fact a site was always chosen where this part of the Upper Lias could be worked without having much of the superincumbent strata to remove, and where the waste shales could be easily got rid of after the material required had been obtained.

There are two sorts of alum employed in commerce, potash alum, and ammonia alum, formed by the combination of sulphate of alumina with the sulphates of potash and ammonia respectively. The former of these was the one principally made in this district. The manufacture was carried on in the following manner.* The broken shale was thrown on a layer of brushwood which was set on fire, and more brushwood and shale added till the heap attained a height of from 90 to 100 feet. Care was taken that the temperature did not rise too high, and moisture was added; by which means oxygen was absorbed, the sulphur contained in the shale became acidified; and sulphate of protoxide of iron and sulphate of alumina were formed. The calcined shale was next steeped in shallow pits, from which the impregnated water was drawn off and mixed with fresh shale, until the proper degree of concentration was obtained. The liquor was then placed in cisterns to allow the greater part of the impurities to settle, after which it was removed to the boiling house and further concentrated, when chloride of potassium was added, which decomposed the iron salt forming protochloride of iron and sulphate of potash, the latter combining with the sulphate of alumina to form alum. The liquid was now allowed to crystallize, by which means the alum was separated from the highly soluble chloride of iron. This after working was again heated and re-crystallized when it was ready for the market. The following analysis of the Alum Shale from Whitby is given in Ure's Dictionary:—

* The process is described by D. Colwall, Phil. Trans., vol. xii., no. 142, p. 1052, 1679; R. Winter, Journ. Nat. Phil., ser. 2, vol. xxv., p. 241, 1810; Young's History of Whitby, p. 806, 1817; also some details in Brit. Assoc. Reports for 1863, p. 709.

—	Top Rock.	Bottom Rock.
Sulphide of iron	4·20	8·50
Silica	52·25	51·16
Protoxide of iron	8·49	6·11
Alumina	18·75	18·30
Lime	1·25	2·15
Magnesia	0·91	0·90
Oxide of manganese	traces	traces
Sulphuric acid	1·37	2·50
Potash	0·13	traces
Soda	0·20	traces
Chlorine	traces	traces
Coal	4·97	8·29
Water	2·88	2·00
	95·40	91·91

Jet.

The working of jet and its manufacture into ornaments has been so largely carried on at Whitby that the name of the town has come to be more generally associated with this trade than with anything else. Jet has been obtained from other places, but that from Yorkshire on account of its hardness and capability of taking a high polish is considered the best. There are, however, many qualities, but the best "hard" jet is only found at one particular horizon in the *serpentinus*-beds of the Upper Lias; the bastard or soft jet which occurs in some of the other beds being scarcely of any value.

Jet was known to the ancients both in this country and elsewhere, as is proved by the ornaments made of it which have been found both in Celtic barrows and Roman coffins. The name is said to be derived from Gagae a town on the coast of Lycia, whence was obtained the mineral called Gagates lapis, but whether this was the same as our jet is uncertain. Solinus and Bede speak of jet being obtained in Britain; the Saxon poet Cædmon who died about 670 or 680, and was buried in Whitby Abbey, also refers to this mineral in the following lines:

> "Jeat stone, almost a gemm, the Lybians find,
> But fruitful Britain sends us wondrous kind;
> 'Tis black and shiny, smooth and ever light;
> 'Twill draw up straws, if rubbed till hot and bright;
> Oyl makes it cold, but water gives it heat."

Jet is again mentioned in the Abbey rolls for 1394. "Itm. p. vij anulis Robo Car de gagate vij *d*."* There is no doubt that it was much used in the days of the Abbey for rosaries and crucifixes, as remains of these have been found in the ruins. The manufacture of jet was carried on at Whitby in the reign of Elizabeth,†

* "For seven rings to Robert Car of jet 7*d*." Robinson's Whitby, p. 302. Bower, Journ. Soc. Arts, vol. xxii., p. 80, also gives the date 1350.

† In the title deeds of a house near the bridge the name and occupation of "John Carlill, Jet worker, 1598" is mentioned. Robinson, loc. cit., p. 94.

the supplies being obtained principally from the loose pieces washed out of the cliffs, but since that time probably from this source failing, the trade appears to have been given up until the early part of the present century, when it was again revived.*

In 1850, there were about 50 workshops, and the following year the trade was brought prominently before the public by a case shown by Messrs. Slater and Wright at the Great Exhibition. Considerable impetus was also given to this trade by the deaths of the Duke of Wellington and the Prince Consort; so that by 1873 the number of workshops had increased to 200, giving employment to about 1,500 hands. The rapid progress of this industry up to 1873 may be seen from the following statement: †

	£
In 1860 the trade realized - - -	45,000
„ 1861 „ „ - - -	50,000
„ 1862 „ „ - - -	53,000
„ 1863 „ „ - - -	55,000
„ 1864 „ „ - - -	57,000
„ 1870 „ „ - - -	84,000
„ 1871 „ „ - - -	86,000
„ 1872 „ „ - - -	88,000
„ 1873 „ „ - - -	90,000

Since then the trade has rapidly declined; in 1882, there were only about 400 men employed, and not more than three to four tons of Whitby jet were used, varying in value from 300*l* to 1,300*l*. a ton; ‡ in 1886 the amount fell to 4,670 lbs. or a little over two tons, which were valued at 934*l*.§ At the present time (1888) there are said to be not more than 200*l*. worth of Whitby jet employed in the trade annually. The principal cause of this decline is the importation of foreign jet; which is of much lower value, and is very inferior in quality; it contains a large proportion of waste, and will not stand extremes of heat or cold.

In 1882, there are stated to have been over 100 tons imported from France and Spain, the value of the former being about 30*l*. a ton, while the latter averaged from 60*l*. to 140*l*. a ton.‖

In former times most of the jet was picked up off the shore, but this becoming soon exhausted, the workers had to mine the cliff and inland escarpments. The remains of these old jet holes are very numerous, both along the cliff and inland, the line formed by the workings indicating the outcrop of the jet-rock very clearly. From the jet itself occurring only in isolated lumps, the mining of it is very precarious, and often attended with loss, there being nothing to guide the miner except the stratum in which it may be expected. This is indicated by a nodular band of impure

* The first workshop for jet is said to have been set up by J. Carter in 1808.

† The above facts are taken from the paper by J. A. Bower, Journ. Soc. Arts, 1874, vol. xxii., p. 80. In 1856 the value stands computed at 20,000*l*. Robinson's Whitby, p. 216.

‡ Parkin, Trans. N. Eng. Inst. Mining Eng. 1882, vol. xxxi., p. 52

§ Mining and Mineral Statistics of the United Kingdom for 1886.

‖ Parkin, loc. cit. Spanish jet is said to occur in the Kimmeridgien.

limestone, know as the "top jet dogger," a short distance below which the best jet is always found. The following account of the manner of working is given by Bower.* "It was formerly obtained in the largest quantity by working in the cliffs, by a process called 'dessing' (very dangerous work), that is by clearing away and hewing down the cliff-sides till jet-ends protruded; the seams were then followed till exhausted. Some seams have realized as much as 1,000*l.* and have been discovered in a short time. At other times, however, men have been employed for weeks, occasionally months, and have found nothing, in fact have been on the point of giving up, when they have unexpectedly come upon a seam that has fully repaid all their labour." Sometimes the mines after having been abandoned by one man are successfully taken up by another. In 1847, Mr. Charles Bryan is stated to have brought up from the North Batts, near Whitby, a seam of jet which weighed 370 stone, and was valued at 250*l.* [? a ton]. Since then M. Snowdon found a deposit at Port Mulgrave, for which 700*l.* was offered.† The largest piece of solid jet in one lump ever found is stated to have been 6 feet 4 inches in length, four and a half to five and a half inches wide, and one and a half thick, weighing eleven pounds and a half. This was offered to the British Museum for 10 guineas, but was afterwards sold for fifteen guineas.‡ The highest price ever given for a single piece of jet is said to have been 21*l.* This piece, which was obtained at Staithes, about 1866, was 2 inches in the thickest part, 7 inches broad, and 6 feet long. It weighed 21 lbs., and belonged to Messrs. Greenbury and Wakefield.

Along the inland escarpments and frequently also in the cliff the jet is worked by drifts made into the hillside, which are seldom more than 100 yards in length. The jet is taken out in as large pieces as possible, and is obtained by pulling down the roof, when the bulk of it is obtained. Owing to the uncertainty of the occurrence of this mineral, it is difficult to fix on a royalty; formerly 2*s.* 6*d.* to 3*s.* 6*d.* per week used to be paid for each miner employed, now it is more usual for the men to pay one third what they make. About 20 years ago, when there were a great number of men mining about Stokesley Banks and Bilsdale, 10*l.* per man or 50*l.* for six was paid as royalty. The principal workings for jet both on the coast and along the inland escarpments are mentioned in the description of the Upper Lias.§

Rough jet is covered with a skin which is blue in the cliffs and brown inland. This skin is removed by chipping with a large iron chisel, the stripped portions are then taken to the sawing bench where they are cut into convenient sizes, after which they are carved or ground into the required shape. The carver, although he can make the most beautiful designs often cannot

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* Loc. cit., p. 82.

† Parkin, loc. cit., p. 52.

‡ Bower, loc. cit., p. 82.

§ See pages 129, 130, 139.

write his own name.* The manufactured articles were formerly polished by rouge and oil; but now, on account of the high price of rouge, rotten stone and lampblack are generally employed. Polished jet is much used for altar frontals, &c. on account of the curious property it possesses of absorbing the radiations of adjacent colours, so that when used with any other colour than yellow, it produces a wonderfully soft effect, and gives a richness of tone which no other black material is capable of producing. Jet bosses worked on a deep crimson ground look like carbuncles.†

It is a matter of much regret that this trade is dying out, and will probably before long become extinct, as these men were capable of producing designs of considerable merit which were frequently copied in other trades. It was thus the means of giving encouragement to very artistic work which will now be lost to the country.

There is considerable difference of opinion as to what jet really is; some authors considering that it is fossilized wood, the structure of which is shown in the blocks of jet; while others state with equal confidence that there is no trace of organic structure in these blocks, but that they are due to the segregation of bitumen from the surrounding shales. It is very certain that jet is derived from vegetation in some form or other; and it is probable that it occurs partly in its original state and partly converted into bitumen which is the principal cause of the great variation in its quality. Prof. Nichol states, that the specimens examined by him from Whitby distinctly showed the peculiar structure of coniferous wood, and might be referred both to the genera of pines and araucaria.‡ Robert Hunt considered that vegetable matter was first converted into fluid bitumen and eventually consolidated into jet, but was not due to the direct conversion from lignite.§ This is the view also taken by Messrs. Tate and Blake.||

Taking it for granted that jet is derived from vegetable matter in some form, the question arises how did this vegetation exist, and what caused it to be deposited in this peculiar manner. It is certain that the plants from which it is formed did not grow on the spot; otherwise the mineral would occur in seams, and not in isolated blocks, and there would probably be some indication of the surface upon which it grew. It must therefore have grown elsewhere, and have been conveyed to these shales by subsequent action. It has been suggested that the marine vegetation of the period was the principal source of the bitumen that occurs in these shales; but, although some carbonaceous matter may be afforded by marine plants, we cannot think that this source alone

* Bower, loc. cit., p. 82.

† Parkin, loc. cit., p. 56.

‡ Rep. Brit. Assoc. for 1834, p. 660, and Edin. New. Phil. Journ., vol. xvi., p. 137. See also Witham, Observations on Fossil Vegetables, 1831 and 1833.

§ Watson, Proc. Geol. Soc. Yorksh. 1861, p. 96.

|| Yorkshire Lias, p. 178.

would be sufficient to supply the large amount of bitumen found in these shales. It seems to us much more probable that the greater portion would be derived from forest-trees that grew on neighbouring land, and which being floated into this position were covered by the Lias shales. These were subsequently converted into bitumen, which became diffused through the neighbouring shales or occupied cavities in them; where it is now found as jet, often occurring as pseudomorphs of organic remains.

Coal.

As we have already, in the stratigraphical description of the Lower Oolite,* given an account of the numerous thin seams of coal which occur in these rocks and shown their geological position, it will suffice here merely to enumerate the principal beds that have been worked, and point out the localities where they are of most commercial importance. All these seams are very thin, it is only occasionally that they swell out to a thickness that is worth working, and even then the quality is so inferior that they are usually only fit for lime-burning; but even for this purpose, since the railways have introduced cheaper and better fuel, their use has been almost entirely abandoned.

The principal seam of the district occurs at from 50 to 100 feet below the Grey Limestone Series. This coal has been worked at a great number of places; but principally along the north side of the Esk between Danby and Lealholm Bridge, where it is 17 inches thick; and over the moorlands to the south of this valley, where it varies from 15 inches north of Rosedale to 2 feet at Blakey House. At Harland it is only about 8 inches thick, but of a better quality; while at Piethorn on Helmsley Moor the coal occurs in two seams 11 inches and 4 inches thick respectively. West of Bilsdale this coal is about 10 inches thick, and has been worked north of Hawnby and on Snilesworth Moor. Along the western escarpment workings occur at Swinestone Cliff, Kepwick, and Kilburn; but the most important mines in this neighbourhood appear to have been at Birdforth and Coxwold; at the former of these places the seam is said to have had a thickness of from 3 to 4 feet, while at the latter it was about 1 foot 4 inches thick. This coal has also been worked on the coast at Cloughton, and at Maybecks where it was only 6 inches thick. On the north side of the Eller Beck at Allan Tofts between Goathland and Grosmont it swells out to as much as 2 feet for a short distance. The coal has been worked on Skelton Hill, but it does not appear to have been much used over the Cleveland district.

The other seams which are found in the Oolites occur near the base of the formation, not far above the Dogger. A seam occupying this position was worked on the coast north of Robin Hood's Bay in 1821, and several tons of this coal are said to have been gathered from fallen blocks near Whitby in 1826. In

* See pp. 192, 223.

Basedale a seam of coal exists about 70 feet above the Dogger which has been worked at the head of that valley. This coal has also been worked in Hartoft Dale near the south end of Rosedale; and in the Howardian Hills between Yearsley and Gilling.

Road-metal, Whinstone, &c.

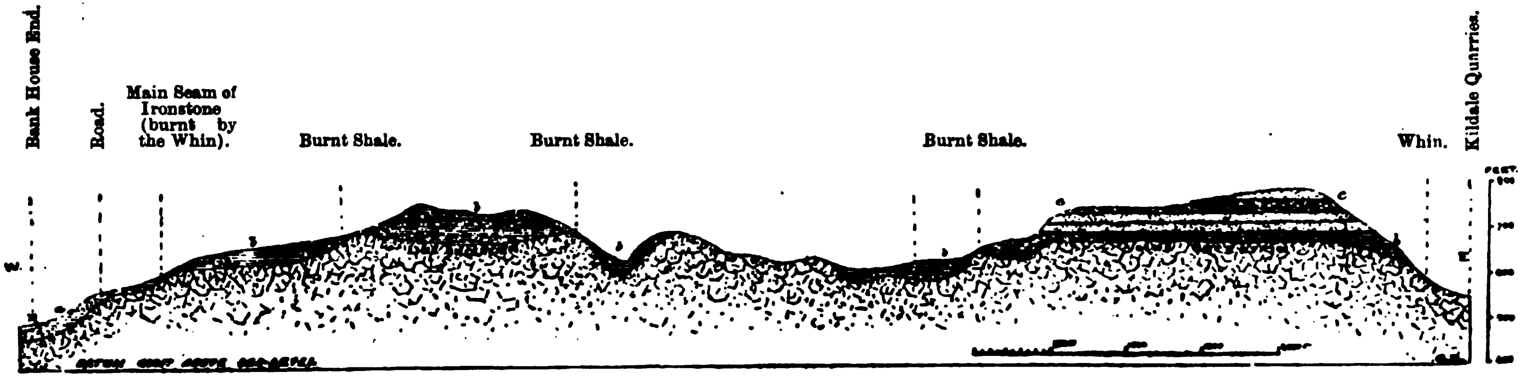
The principal road-metal of this district is undoubtedly the Whinstone,* which is obtained from the great basaltic dyke that traverses the Jurassic rocks in a direction nearly E. by S. from the neighbourhood of Stainton and Ayton in Cleveland to Fylingdales Moor, not far from the coast at Robin Hood's Bay, where it finally dies out or at least does not reach the surface. The thickness of the dyke varies considerably in different places, and also at different levels; thus at the top of Cliff Ridge near Ayton it is only 20 feet wide, whereas in a level driven through it at the bottom of the hill 80 feet were proved. The upper surface is also very irregular, the rock frequently disappearing for some distance where it has failed to penetrate the Oolitic strata, as is shown in the accompanying section taken along a portion of its course. The general course of the dyke is remarkable straight, but there are a few sharp bends as near Ayton, and also where it crosses the Tees.

The dyke after traversing the county of Durham enters Yorkshire opposite Preston Hall between Stockton and Yarm. In crossing the valley of the Tees it is only seen at a few places, but soon after entering the Lias shales it forms the well-marked ridge known as Cliff Ridge near Ayton. On the east side of this hill it s lost for a time; and the covering of sand makes it doubtful where it again crops out, although there is a large quarry of the rock in Slacks Wood. Just beyond this it must again sink beneath the surface, reappearing only at one point in Howl Road. The calcined Ironstone and several trial-holes show that it has just failed to burst through the solid rock here. After being quite covered for some 300 yards or more, it is seen again for some little distance at Stone Ruck, but its breadth is not more than 20 feet here. Further up the hill a few patches of calcined shale show that it is close to the surface, but in the Oolite capping of Coates Moor it makes no show. Descending into Kildale, it is quarried once more, but for some distance is hardly as much as 20 feet broad. Close by Wood End it is covered by Drift for a short distance, and when it reappears it contains a considerable amount of pyrites, the decomposition of which probably gives rise to the sulphuretted hydrogen spring that issues from the dyke close to the railway bridge. A small outcrop of "whin" is seen on the south side of the railway, near the old fish pond, after which it disappears for more than a mile. Due south of Wayworth is a small scar, in which the dyke may

* Most of the information in this account of the whinstone dyke is derived from that given by Mr. Barrow in the Memoirs of the Geological Survey, Explanations of Quarter-Sheets 96 N.E., and 104 S.W.

Fig. 25.

Section along the Cleveland Dyke, north of Kildale.



Vertical Scale three times the Horizontal.

Section to illustrate the irregular upper limit of the the Cleveland Dyke. From near Bank House (one mile N N.W. of Captain Cook's monument), through the head of Lonsdale, over the east end of the Oolitic Outlier, on which the monument stands, to the quarries at the junction of Kildale and Lonsdale.

× Drift. *a* Middle Lias. *b* Upper Lias. *c* Lower Oolite.

be followed for about 50 yards, again plunging beneath the surface. Some burnt shale marks its position further east, but the dyke itself does not appear till nearly the top of Kempswithen is reached; from this point it is visible for a considerable distance to the east. It is lost again at Danby Park, between which place and Ainthorpe it is either absent or hidden by Drift for there are no exposures of the solid rock. At Ainthorpe it appears for about 150 yards, when it is again lost beneath the Boulder Clay that fills the Esk valley at the foot of Fryup Dale; but reappears at West Mire Howe near Lealholm Bridge, and may be traced thence continuously as far as the Glaisdale Ironworks. Between this and Egton Bridge it is not seen, being probably hidden by the great amount of Boulder Clay which fills the valley here. East of Egton Bridge the outcrop of the Whinstone Dyke is well exposed across Lease Rigg, in the valley of the Murk Esk, on Sleights Moor, on Sneaton High Moor, and Fylingdales Moor, and in fact is very distinct until it is finally lost just east of Blea Hill. In this part of its course it has been extensively quarried and sent away by rail, a tramway having been made to connect these works with the station at Goathland. It here again forms a well-marked ridge, which has been chosen as the site of numerous howes or tumuli.

The whinstone is a bluish grey or nearly black finely crystalline rock, being rather compact and having a tendency to a conchoidal fracture. It consists of a ground mass apparently made up of augitic and felsitic matter, with small crystals of felspar and augite. Scattered through this are glassy crystals of triclinic felspar of much larger size, very distinctly visible to the unaided eye, and which give the rock a distinctive character by which it can be easily recognised. Mr. J. J. H. Teall has given a detailed account of the mineralogical structure of this rock, from which the following analyses are taken:—*

Silica	57·57	59·25
Alumina	14·25	16·75
Ferric oxide	6·04	4·00
Ferrous oxide	3·95	4·82
Manganese oxide	·27	—
Lime	6·87	6·88
Magnesia	4·24	3·81
Potash	1·08	1·92
Soda	2·98	2·56
Sulphur	1·9	—
Carbonic acid	·30	trace.
Phosphoric acid	·15	—
Water	1·25	—
	99·14	99·99

This gives an average of about 58 per cent. of silica, which is much higher than that of a typical basalt. The specific gravity also is lower, being only 2·77. In consequence of this, Mr. Teall proposed to call this rock an augite-andesite, and compared it with specimens, similarly named, from various parts of Europe.

* Quart. Journ. Geol. Soc., vol. xl., p. 224.

The rock has been quarried at most places where it comes to the surface, and when at any depth is frequently mined.* These sections show some interesting facts.

The dyke most clearly does not lie in a line of fault, and after the molten rock had cooled it seems to have dragged down the beds against its sides, the strata having a sharp dip into it for several yards. The rock at the junction with the sedimentary strata is decidedly finer in grain and contains fewer felspar crystals than in its centre. It is, moreover, almost flaggy at the edges, the long flaggy faces being parallel to the sides of the dyke. The sedimentary strata are altered or calcined by it for a distance of two or three yards from the point of junction. At the outcrop this rock occurs in rounded blocks with tough brown coatings which may be peeled off in concentric layers; the decomposition from which this arises generally extends right through all the smaller blocks, but there is a decided difference in its amount, due entirely to the beds in which it occurs. Between the beds of Oolitic sandstone, which allow the free admission of water, the whinstone is much decomposed; but in the Lias shales, which are almost impervious, it is comparatively unaltered, and is extensively mined in consequence. The rock, where reached in levels at about 500 feet below the surface, occurs in very large blocks about the centre of the dyke, and even the junction faces show little signs of weathering.

Although much inferior to the whinstone, many of the harder beds of the Jurassic rocks are also used for mending roads throughout the district. In some localities the calcareous beds of the Grey Limestone Series also form a very good roadstone. This is particularly the case at Spindle Thorn on Spaunton Moor; where the rock, being more than usually calcareous, is very dark in colour and finely crystalline in texture; which gives it, when freshly broken, much the appearance of whinstone.† These beds are however usually too much decomposed near the outcrop to be of any value, and it is only at a very few places that they are employed. Belonging to this same series is the well-known "Brandsby roadstone," which was formerly extensively quarried in the western part of the Howardian Hills between Brandsby and Gilling; but which, since the introduction of railways, has been largely superceded by whinstone. The Grey Limestone Series in this district is much more arenaceous than about Spaunton; the lower part, which is that quarried for roadstone, consisting principally of hard siliceous flaggy sandstones.

The next most important road-metal is the sandstone which occurs irregularly in wedge-shaped masses in the upper part of the Moor Grit, or just over it. This rock, which is locally known as "White flint," is so fine grained and compact as to be more

* 43,601 tons of "whinstone," including 70 tons of ganister, were worked in 1886. The value of which is estimated at 4,448*l*.

† A portion of these beds which crops out on the coast at Hundale Point near Cloughton has been mistaken for whinstone; and this is no doubt the reason why on many old geological maps the outcrop of the basaltic dyke is represented as continuing through to the coast.

like a quartzite than a sandstone of the Estuarine Series; it is extensively used over the district north of the Esk. On the high moors to the south of that river the presence of this rock is indicated by the large white blocks called "Crow stones,"* which strew the ground in some parts.

At Ayton and Hackness near Scarborough the crystalline limestones of the Coral Rag at the top, and the Coral Bed at the base of the Coralline Oolite, are used as roadstones. The former of these is, however, a very inferior material; being soft and white it forms roads very similar to those in a Chalk country. The latter is only employed to a very limited extent.

The Passage Beds below the limestone are also very generally used along their outcrop, for the less important roads throughout the Tabular range and in the Howardian Hills; but the stone is scarcely tough enough to withstand much traffic, and is not generally employed for the main roads of the district, where the preference is given to whinstone.

The siliceous doggers† and harder beds of the Calcareous Grit‡ are sometimes used for road-metal, and Hudleston mentions§ that the ironstone of Rosedale Abbey was at one time employed in this manner. Besides this some of the other thin beds, such as the Millepore Bed at Westow, and the Hydraulic Limestone near Whitwell and Hotham, are quarried locally for this purpose. Along the outer flanks of the Oolite hills the gravel and boulders out of the Drift is the principal source of road-metal.

Building Stone.

The Jurassic rocks of north-east Yorkshire afford many valuable building stones which are obtained from the following beds:—

The Upper Calcareous Grit (North Grimston Cement-stone).
The Upper Limestone.
The Middle Calcareous Grit.
The Passage Beds.
The Lower Calcareous Grit.
The Kellaways Rock.
The Upper Estuarine Series (The Moor Grit).
The Middle Estuarine Series.
The Millepore Bed and the Cave Oolite.
The Lower Estuarine Series.

The first of these, the North Grimston Cement-stone, is only developed to a very limited extent; and, consequently, is only employed locally in the neighbourhood of Langton, Birdsall, and North Grimston, where it crops out, and is occasionally used for farm-buildings, &c. It breaks up into short flaggy pieces; which, although forming a fairly even wall, are not suited for very large

* Young's History of Whitby, p. 665.

† These doggers are extensively used in the neighbourhood of Scarborough, being collected from the fallen blocks along the shore, and brought to that place in boats.

‡ On the edge of the escarpment overlooking Bilsdale the cherty beds of the Calcareous Grit form a talus of angular gravel, which is there employed as a road-metal.

§ Proc. Geol. Assoc., vol. iii., p. 305.

buildings. Wharram Church which is situated some way up one of the Chalk dales is built of this rock, probably because it was the nearest stone available. This rock has been quarried at Snape Hill near Kilburn, where it is passing into the more arenaceous state of the true Upper Calcareous Grit; but whether the rock was employed for any purpose, or merely removed to reach the limestone below, we do not know.

Both the Upper and the Lower Limestones may be occasionally used as building-stone, but they are, as a rule, too soft and friable ever to be of much value, except that peculiar form of the rock which occurs at Hildenley.* This bed, which is considered to be the equivalent of the Coral Rag, is the best stone for interior or ornamental work in the district. It consists of a fine-grained limestone, which is well adapted for carving, except that a small silicified *Ostrea* occasionally occurs in the stones which interferes with its free working. This limestone was employed for the interior work of Kirkham Abbey; the fine state of preservation of the mouldings in these ruins, which have been exposed to the weather for many centuries, testifies to its durability as a building-stone. The chapel at Castle Howard was also built of this stone.

The Middle Calcareous Grit, as we have shown in the stratigraphical account of the rock, attains its greatest thickness, and most massive character, at the western end of the Vale of Pickering, on either side of the river Rye above Helmsley. It here forms massive beds of freestone, which were employed in building the mansion at Duncombe Park and the college at Ampleforth. This rock has also been worked at Pickering, where, in like manner, it forms good beds of freestone, but is occasionally rather shelly.

The Passage Beds and some of the harder beds of the Lower Limestone are frequently used for field-walls and inferior buildings. This is particularly the case in the neighbourhood of Hackness, where on this account the rock is locally known as "Wallstone." It is a course rubbly stone generally splitting up into large slabs. Shallow quarries in this rock are numerous along its line of outcrop in the northern part of the Tabular Hills between Hackness and Kirk Dale.

The Lower Calcareous Grit is employed as a building-stone along the whole range of its outcrop from the coast at Scarborough to the Hambleton Hills, and throughout a great part of the Howardian Hills. It is however usually too soft to be of much value, and is certainly inferior to many of the other beds which are found in the district. The rock, although thinner in the Howardian Hills than along the Tabular range is more compact, and consequently all the most noted quarries in it occur along the southern outcrop.† These are Park Quarry at Castle

* The freestone beds at Hovingham are also probably on this horizon, but they are not worked at the present time.

† The stone for Sheriff Hutton Castle was probably obtained from this rock. It is said to have been conveyed in boats across the low ground, then a lake, between the Oolite hills and Sheriff Hutton.

Howard, Brows Quarry at Malton, and Birdsall Quarry, at all of which the stone has been worked for important buildings.*

The Kellaways Rock, although the area over which it is compact enough to be worth working is limited, has nevertheless supplied some of the best freestone in the district. When first quarried it is easily worked, but hardens on exposure to the air, and forms a durable building-stone, as is evinced by the Church and Hall at Hackness, the Museums at York and Scarborough, and other structures in which this stone has been employed. The principal quarries are at Hackness and Levisham, but they have not been much worked of late years. This rock, as we have noticed, is very massive in the valley of the Riccal, in which neighbourhood we think it might be worked with advantage.

We now come to the sandstones of the Lower Oolite; these are largely employed for building purposes; and, being as a rule, coarser in texture, and more massive, are suitable for structures where great strength is required, and also for general outside work.

The Upper Estuarine Series has at its base an important bed of sandstone, the Moor Grit, which is well developed throughout the whole of the northern and moorland district from the coast to the western escarpment. It varies in character from a fine-grained sandstone to a coarsish grit; its outcrop is nearly always well marked, frequently being indicated by a line of crags. The rock has been worked at places too numerous to mention, but perhaps the most noted quarries are those at Cloughton, where it has been employed as an ordinary building-stone for a number of years, and the one at Old Fold at the head of Riccal Dale, where the rock is very strong and massive, and was employed in building the railway bridges of the Helmsley branch of the N.E. Railway. In some places the sandstone splits into slabs often of great size and furnishes a good flagstone; that is the case near Whitby where the quay is paved with large slabs obtained from this rock.

The Grey Limestone has been used at Scarborough in the formation of the harbour pier; for which reason it was called by Smith, Murchison, and others "Pierstone." Although the rock can scarcely be called a building-stone, the more calcareous beds can be obtained in large blocks which are suitable for structures such as piers or breakwaters where no smoothness is required.

The Middle Estuarine Series usually contains only thin bands of sandstone interstratified with shale, but occasionally these swell out into more important beds which afford good building-stone. This is the case at Hayburn Wyke, where one of these bands suddenly attains a considerable thickness for a short distance, and has afforded a stone of a very fine quality, which has lately

* Bewick states that the railway stations at Malton and Pickering are built of this stone; but he does not mention the quarries from which it was obtained, and may be referring to the Middle Calcareous Grit which is quarried in the neighbourhood of the latter place. Geological Treatise, p. 79.

been employed in building the clock tower of the railway station at Scarborough. One of the beds in the upper part of this series is mentioned by Young and Bird as being quarried at Cloughton for flagstone*; but this bed has not to our knowledge been worked for some time. Some thin beds have also been worked to a limited extent in the escarpment above Kirkby Knowle.

The Millepore Bed and Cave Oolite, although geologically the same formation, are very different rocks when viewed commercially. The former, where it occurs along the coast south of Scarborough, and has been employed in the construction of the pier to the harbour at that town, is a very hard siliceous rock, breaking up into rough irregular blocks, which are well suited to the formation of breakwaters and other structures, where great strength, but no evenness of surface, is required.

The Cave Oolite, which is a very different class of rock, being a soft sandy oolitic limestone, has been occasionally used in the neighbourhood of Brough for interior work, being called "Cave Marble." The stone from these quarries was employed in the construction of the Hull dock, and in earlier times for the monasteries of Holderness.

The Lower Estuarine Series crops out over a large district extending along the coast from Staintondale northwards, and thence curves round by the northern and western escarpments, besides occupying a large portion of the interior moorlands. It consists mostly of thick beds of massive sandstone, especially towards the lower part, which have been quarried at numerous places, but more particularly at Aislaby, where are perhaps the most celebrated quarries in the whole district. From these quarries the stone was obtained which was used in the construction of Whitby Abbey, Covent Garden Market, the foundations of Waterloo Bridge and London Bridge, the piers of Whitby, Ramsgate, and Margate, and many other well-known structures.† This rock has also been worked at Shaw End, south-west of Lealholm Bridge, from which quarries the stone has according to Bewick been sent to London.‡ In Rosedale, flagstone of exceptional quality is obtained from this series. The good state of preservation of the stonework of Guisbrough Abbey and Mount Grace Priory also attests the durability of these sandstones.

Tufa, the calcareous deposit from springs strongly charged with lime carbonate, often occurs along the foot of the Tabular Hills. This rock, although strictly speaking not a building-stone, is frequently used for rockeries and such-like ornamental work, and therefore may be mentioned in this place. The principal deposits of this stone are at Kepwick, in Newton Dale near

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* Young and Bird, p. 111.

† *See* Report with reference to the Selection of Stone for building The New Houses of Parliament, 1839. 27,424 tons of block-stone were shipped from Whitby in the year 1847. Robinson's Whitby, p. 223.

‡ Geological Treatise, p. 104.

Saltergate, in Troutsdale, and in the upper part of Forge Valley; from which last the rock was obtained for the tanks of the Scarborough Aquarium.

Cement.

The principal sources of cement are from the North Grimston Cement-stone overlying the Coralline Oolite, and from the argillaceous nodules in the upper part of the Lias. The first of these, which is a close-grained argillaceous limestone, occurs, as we have before stated, in the district south of Malton between the villages of Langton, North Grimston, and Birdsall; and, although representatives of this bed are found also at Hildenley and near Kilburn, it is only here that it is likely to be of any commercial value. It forms a lime which, from its similarity to that obtained from the Lias of the South of England, has been called "Blue Lias Lime," or "Lias Hydraulic Lime." The following is the analysis of this limestone compared with that from Lyme Regis*:—

——	North Grimston.		Lyme Regis.
Lime - - - - - -	45·74	82·0	81·50
Carbonic acid - - - - -	36·26		
Magnesia - - - - - -		0·29	—
Alumina, silica, &c. - - - -		16·96	17·80
Moisture - - - - - -		0·69	0·69
		99·94	99·99

This cement has been employed in many important works at Scarborough and elsewhere, more particularly for the foundations of the Grand Hotel, the tanks of the Aquarium, the Spa Buildings, the Gas Works, the Waterworks, the North-Eastern Railway, and other works.†

Another source of cement is that obtained from the nodules in the upper part of the Upper Lias, which occur throughout about 20 feet of shales near the top of the formation. These nodules, when calcined and ground, or stamped to powder, form a Roman cement. They are obtained from the Alum Works, and have been worked at Sandsend, Lofthouse, Peak, and Grosmont,‡ but principally at the former. Their occurrence is, however, rather irregular, and they do not appear to be present either at Kettleness or Saltburn.

The section at Sandsend is:—

	Ft.	In.
Oolite Rock.		
Soft shales - - - - - - -	4	0
Shales with cementstones - - - - -	20	0
Alum shales below.		

* The first of these analyses is by Pattinson, the latter is taken from Reid's Practical Treatise on the Manufacture of Portland Cement, p. 8.

† This stone was first used about the year 1856. I am indebted to Mr. J. Abbott, the proprietor of the North Grimston Quarries, for the above particulars and analyses.

‡ Belcher, loc. cit., p. 39.

The following is the analysis of this cement by Dr. Richardson:

Clay insoluble in acids { consisting of silica 12·24 ; „ „ alumina 6·17 }	-	18·41
Alumina soluble in acids	-	6·89
Oxide of iron	-	0·54
Lime	-	37·68
Magnesia	-	5·20
Soda and potash	-	trace
Organic matter	-	1·45
Carbonic acid and water	-	29·62
		99·79

"About 20 cwt. of this mineral is found in every 60 tons of shale, and the greater proportion is sent to Hull, where it is manufactured into a cement, sold under the name of Mulgrave cement. The mineral is burnt in small open kilns, and afterwards ground to a fine powder."*

The manufacture of this cement under the name of "terras" was first started in 1811. The first steam engine introduced into Cleveland was used for grinding these calcined nodules.†

The Hydraulic Limestone which crops out throughout the Howardian Hills, and is of some importance near Whitwell, is also a cement-stone, but we are not aware that it has ever been employed in the manufacture of cement. Parkin alludes to a cement-stone about 2 feet thick in the Rosedale neighbourhood which appears to be at about this horizon.‡

Limestone.

Limestones occur at five or six horizons in the Jurassic rocks and have been burnt for lime. The principal of these is undoubtedly the Upper Limestone, which crops out along the lower slopes of the hills encircling the Vale of Pickering. This rock is utilized along the whole line of its outcrop, but the principal quarries are those at Seamer, Pickering, Malton, and North Grimston.§ from the three latter places the lime is sent away by rail, while from the Pickering quarries much of the stone is used as a flux for the ironworks. The following analysis of the Malton stone is given by Lucas (Brit. Assoc. Report for 1844, Trans. of Sections, p. 31):—

Carbonic acid	-	44·35
Lime	-	53·53
Red oxide of iron	-	0·69
Insoluble matter	-	1·26
Loss	-	0·17
		100·00

The Lower Limestone has also been burnt for lime to a considerable extent, but not nearly so largely as the higher bed. It

* Brit. Assoc. Reports for 1863, p. 713.

† Young's History of Whitby, p. 818.

‡ Trans. N. Engl. Inst. Eng., xxxii., p. 52.

§ We are here referring to the limestone from the west quarry, the rock from the east quarry has already been alluded to under the head of Cement.

is in general a good oolitic limestone, but in many places is very arenaceous, and frequently has a tendency to become siliceous. For this reason, and also probably because the outcrop of the rock is less accessible and at some distance from the most populous districts and best cultivated land, it is only locally used on a small scale. The rock has been principally worked at Thornton Dale, Cropton, and near Gillamoor, but small quarries are numerous from Scarborough to Hambleton. The following analyses of six samples of limestone from Deepdale between Appleton and Hutton are given by Parkin.*

Sand clay, &c.	9·00	6·40	5·10	3·00	4·10	6·60
Carbonate of lime	89·40	92·40	94·40	96·20	94·50	92·50
Carbonate of magnesia	·50	·75	·75	·20	·70	·50
Moisture	1·10	·45	·45	·60	·70	·40
	100·00	100·00	100·00	100·00	100·00	100·00

This limestone is also very largely quarried at Kepwick, where it is employed chiefly for agricultural purposes. Analysis gives† :—

Carbonate of lime	86·00
Carbonate of magnesia	6·20
Alumina, &c.	0·03
Silica	7·77

Young and Bird also give two analyses of this limestone‡ :—

——	Thornton.	Lockton.
Carbonate of lime	37·1	32·3
Silex and alumina	59·6	63·7
Oxide of iron	2·5	2·9
Water	·8	1·1
	100·0	100·0

The more calcareous beds of the Grey Limestone Series, although much inferior to the limestones of the Coralline Oolite just mentioned, have been occasionally burnt over the greater part of the moorland district. These beds are generally very siliceous; and, unless care is taken in regulating the heat, are liable to become fused, the whole contents of the kiln running to a slag. This limestone is consequently only used to a very limited extent in districts remote from railways or the outcrop of

* Trans. N. Eng. Inst. Eng., 1883, vol. xxxii., p. 50. It is doubtful which division of the Coralline Oolite is referred to.

† Milburn, Trans. Roy. Agri. Soc., 1848., vol. ix., p. 516.

‡ Geological Survey of the Yorkshire Coast, 2nd edit., p. 111. These analyses were procured by the proprietor, James Wilson, Esquire, of Sneaton Castle, from the Royal Institution.

the purer beds. The following analyses of this limestone from Maybecks and Commondale are taken from Young and Bird, except that by Prof. Henry which is given by Pratt.*

	Maybecks.				Commondale.	
	No. 1.	No. 2.	No. 3.	No. 4.	No. 1.	No. 2.
Carbonate of lime	55·6	77·6	98·1	69·0	34·9	33·7
Silex and alumina	40·6	18·9	·6	24·3	61·0	63·4
Oxide of iron	2·8	2·5	·8	2·7	3·0	2·0
Water	1·0	1·0	·5	4·0	1·1	·9
	100·0	100·0	100·0	100·0	100·0	100·0

"The relative proportions of silica and alumina in these specimens are not stated, except in regard to No. 4 of the Maybecks or Sneaton Limestone, which, in the 24·3 parts of silica and alumina, contained in 100 parts of the limetone, was ascertained to yield 16·1 of silica and 8·2 of alumina. No. 3 of the same limestone is remarkable for its large proportion of carbonate of lime, being no less than 98 parts in 100 of the stone. In this specimen there was found a slight trace of magnesia. It ought to be observed that this specimen and No. 2 of the Sneaton limestone, and perhaps we may add No. 4, may be considered as choice specimens, superior to most of the blue limestone of our district."

	Commondale. Prof. Henry.
Carbonate of lime	44·8
Silica	51·4
Alumina and oxide of iron	2·6
Water, &c.	1·2
	100·0

The analyses from Maybecks were from picked specimens, and are far superior to the average of this stone.

In the Howardian Hills and in South Yorkshire about Cave, the Oolite Limestone, which is the equivalent of the Millepore bed, is the principal source of lime. This rock is somewhat extensively used near Whitwell, and in a less degree at other places in that neighbourhood, as well as along the Wold-foot between Sancton and Brough-on-the-Humber. In this latter neighbourhood Mr. Allison gives the following analysis :—

Carbonate of lime	76·40
Silica	18·10
Alumina	2·82
Iron peroxide	1·43
Carbonate of magnesia	1·21
Water	0·06
Total	100·02

* Geologist, vol. iv., p. 95.

The Hydraulic Limestone has been burnt at Terrington, and is said to make a good agricultural lime; but we are not aware that it has been tried elsewhere; probably the bed is too thin ever to be worked with profit.

The Dogger has been burnt in the Stokesley Hills, at Sutton-under-Whitestonecliff, and a few other places, but it is only in the west, and even there very rarely, that this bed is calcareous enough to be considered a limestone. It also contains so much silica that, like some of the beds of the Grey Limestone Series, it has a great tendency to run to a slag.

Bricks, Tiles, and Pottery.

Many of the shales of the Jurassic rocks, as well as the Boulder Clay which overlies them in certain parts, are used for making bricks, tiles, &c. The best material is obtained from the Estuarine Series, which consist of irregular beds of shale and thin sandstones. These when ground up and mixed in suitable proportions form very good bricks, tiles, &c. In some cases sanitary pipes, flooring tiles, and a coarse kind of pottery have been made from these clays. The principal works are at Scarborough, at Egton, and at Skelderskew on Commondale Moor. At the latter place there is fireclay said to be of some commercial value.

Along the sea-coast and in Cleveland the Boulder Clay has been very generally used for brickmaking, while in the Vale of Pickering, at Hildenley, North Grimston, and Birdsall, the Kimeridge Clay has also been employed for this purpose, but at the latter place these shales were found unsuitable.

In the Howardian Hills Hudleston has noticed* a seam of very fine potters-earth which is seen in the quarry in Cram Beck associated with the limestone of the Millepore Series. This bed is said to have been employed by the Romans in the manufacture of pottery; the remains of which and portions of kilns having been discovered in the neighbourhood.

Young and Bird mention that some of the shales of the Estuarine Series are capable of being baked into hard slabs without previously working them into a plastic state. This is the case in Tripsdale, one of the branches of Bilsdale, where the shale "has a dark brown colour, and a soapy feel; and is easily divided into thin plates, which in their recent state are soft and elastic, but when prepared by being roasted in hot turf ashes, are used by the inhabitants of the neighbouring vales for baking cakes, being capable of bearing the heat of a common fire for several years. From the use to which these plates are applied, the ravine where they are obtained is called Bakestone-gill."†

Rarer Minerals.

The other mineral substances which occur in the Jurassic rocks are not found in sufficient quantity to be of much commercial value. They have, however, a scientific interest, and therefore

* Proc. Geol. Assoc., vol. iii., p. 327.

† Geol. Survey of the Yorkshire Coast, 2nd edit., p. 120.

may be mentioned in this place. With the exception of iron the other metals occur so very rarely, or are so disseminated through the rocks, that the per-centage is far below that which is worth working

ZINC.—In the form of blende, zinc is perhaps the most plentiful of these rarer metals. It is found in considerable quantities in some portions of the Lias, especially in doggers in the upper part of the Lower Lias, surrounding organic remains, which latter are sometimes entirely composed of this mineral.

A considerable amount of zinc also occurs in the ironstone, as is shown by the following analysis of mineral substances sublimed by the iron furnaces. These form a deposit of a dark grey colour and impalpably fine in the tubes conveying the waste gases. In one case the deposit was obtained from a furnace smelting a mixture of Upleatham and Rosedale ironstones with Weardale blue limestone and South Durham cokes, and was found to contain:—*

Protoxide of iron	14·22
Oxide of zinc	10·48
Sulphide of zinc	13·70
Alumina	8·20
Lime	12·32
Magnesia	5·03
Chloride of sodium	4·74
Ammonia	0·70
Thallium	trace
Sulphuric acid	3·18
Free sulphur	0·17
Silica	22·60
Carbonaceous matter	4·50
	99·84

Pattinson states, that in a sample of ironstone from the Main Seam he obtained an amount of oxide of zinc equal to 0·32 of a grain of zinc per lb. of ironstone, or about 10 grains per ton. The ironstone also contained 0·72 of a grain of nickel and 0·12 of a grain of cobalt per lb.† Titanium is also present in this ironstone in small quantities, as we have mentioned on page 444; and Thallium has been found in sand from the neighbourhood of Whitby.‡ These latter are interesting as showing the wide distribution of comparatively rare metals.

PYRITES.—This mineral occurs in great abundance throughout the Lias, and to a lesser extent in the Oolites; but, the chemical manufacturers obtaining their supplies of sulphur principally from the Coal-measure shales, or from foreign localities, it has not been put to much practical use. The principal horizon of this mineral in the Jurassic rocks is the so-called "Sulphur band,"

* Brit. Assoc. Reports for 1863, Trans. of Sections, p. 48.
† *Ibid.*, p. 49.
‡ *Ibid.*, for 1864, Trans. of Sections, p. 41.

which occurs at the top of that portion of the Main Seam that is worked at Eston; here it has a thickness of from a mere line to 7 inches, and is used in a manufactory at Middlesborough. An analysis of this bed is given in the Table on page 445. At Hutton Low Cross the sulphur band is 4 ins. thick, and, according to Crowder, "contains 30·25 per cent. sulphur, which is equal to 56·71 per cent. bisulphuret of iron, and is about the same quantity as is found in the Wicklow pyrites, used on the Tyne in the manufacture of oil of vitriol."*

COPPER.—Marshall states that copper has been smelted at Hackness, but we have not been able to find any other mention of this; it is very doubtful if copper ore occurs in this district, even in minute quantities.

MAGNETIC IRON SAND.—This is found at one or two places on the coast; especially at Cayton Bay and opposite Peasholm Beck just north of Scarborough. It appears to be derived from the Boulder Clay, but its source has never been exactly ascertained. Winch considered that this might be Iserine, which is a titanate of iron; so that the original source of this sand is possibly the Cleveland ironstone.

LEAD AND BARYTES.—Messrs. Young and Bird mention the occurrence of galena and sulphate of baryta in the Alum shales at Egton, where these have been altered by contact with the basaltic dyke. They also state that galena occurs in slender veins in the Dogger between Whitby and Saltwick.† Parkin states that lead ore has also been found in the Rosedale district.‡

PETROLEUM.—Mineral oil has been obtained from the Jet shales of the Upper Lias at Kettleness, but the workings were soon abandoned as unprofitable.§ There is no doubt, however, that a considerable amount of bituminous matter exists in these shales, as petroleum is frequently found in the joints of the rocks, and in the interior of nodules and fossils; it also exudes from the rock in some of the ironstone mines, and occasionally gives rise to "blowers" of inflammable gas in such considerable quantities as to be burnt.

From experiments with Whitby jet it has been found that 100 grms. of jet evolve 30·2 c.c. of gas at 100°, of which the following is the chemical composition‖ :—

Carbonic anhydride	10·93
Quartane or ethyl	86·90
Nitrogen	2·17
	100·00

* Edin. New. Phil. Journ., 1856, p. 290.

† Young and Bird, loc. cit., 1st Edit., p. 124, and 2nd Edit., p. 182. Prof. Daubrée mentions the occurrence of barytine on the surfaces of fossils at Whitby. Bull. Soc. Géol. de Fr., 1871, p. 322.

‡ Trans. N. Engl. Inst. Eng., 1883, vol. xxxii., p. 52.

§ Phillips, Geol. Yorksh., p. 153.

‖ Thomas, Chem. Journ. 1876., p. 150.

When there is not much cover this "oil" and gas escape to the surface, but when there is a good thickness of superincumbent rock it is forced into the ironstone workings. Ten gallons of oil can be extracted from one ton of shale. This oil, when burnt, is said to give out a clear and brilliant light.*

SCARBROITE.—This mineral is a hydrous silicate of alumina, but remarkable for the very small quantity of silica it contains, in which respect it approaches the constitution of Schrötterite. This mineral was first discovered by the Rev. W. Vernon Harcourt, who gives the following analyses of it† —

Silica - - - -	10·50	7·90
Alumina - - - -	42·50	42·75
Oxide of iron - - -	0·25	0·80
Water - - - -	46·75	48·55
	100·00	100·00

It occurs principally in the upper part of the Grey Limestone and in the Estuarine Series above, in small veins lining the joints and fissures which traverse the rock in various directions. The exact chemical change, which takes place in the rock by which this mineral is produced, has not yet been satisfactorily determined, but it is probably induced by the organic remains.

Hudleston mentions a somewhat similar substance, which is found replacing the shell of the fossils from the Millepore bed of Cloughton.‡ This mineral, although resembling Scarbroite in appearance, is much softer and more friable, as well as differing very considerably in its chemical composition. The analysis is:—

Silica - - - - - - - -	45·98
Alumina - - - - - - - -	38·22
Lime and Magnesia - - - - - - -	1·50
Water and organic matter - - - - - -	14·40
	100·10

SAND, OCHRE.—Messrs. Young and Bird notice the occurrence of a very sharp clean sand, which is composed of fine white quartz crystals with scarcely any cement or matrix, formed by the decomposition of the Moor Grit at Hunt House near Goathland.§ This sand is stated to be used by the farmers for sharpening scythes, &c. Yellow or brown ochre, which is formed from the decomposition of the ironstone, is sometimes found in the neighbourhood of the whinstone dyke, and also occurs in narrow seams and nodules at many places along the Cleveland escarpment. At Rud Scar, near Ingleby Greenhow, there is a seam of red ochre or ruddle, which was formerly used by the farmers for marking their sheep.

* Bower, Journ. Soc. Art, vol. xxii., p. 82.
† Phil. Mag., vol. v., p. 178.
‡ Proc. Geol. Assoc., vol. iii., p. 308.
§ Young and Bird, Geol. Survey, 2nd edit., p. 105.

CHAPTER XIX.

ECONOMIC GEOLOGY—(*continued*).

Agricultural Geology, Soils, &c.

Soils from their character may be classed according to various designations; thus from their composition they are spoken of as clays, loams, sands, gravel, and peats; from their texture as heavy, stiff, and impervious, or light, friable, and porous; from their tendency to retain moisture as wet and cold, or dry and warm; according to their fertility as rich or poor; and lastly, from the particular crops which are best suited to certain lands, clays are spoken of as wheat or bean soils, and friable ones as barley or turnip soils. The colour, consistence, and depth of soils are all valuable indications of its fertility; and although these may be ascertained without much knowledge of the nature of the rocks below, still geology explains why they exist, and points out how far they are likely to extend. It is a well-known fact that the soils of any district partake very much of the character of the rock upon which they lie, consequently they vary in a general manner, according to the geological formation that is immediately beneath them. Soils being derived from the disintegration and decomposition of the rock with a mixture of vegetable and animal remains it follows that in a district like the present its character will be exceedingly varied.

It has been found by chemical investigation that soils possess in different degrees the property of absorbing various substances and of retaining them for the nourishment of crops, as well as of effecting important changes in different manures. Thus, as Dr. Voelcker has pointed out, "lime not merely acts beneficially on sandy soils in a direct manner, by supplying a deficient element of nutrition, but it also preserves in the soil the more valuable fertilising matters, which, like the salts of potash or ammonia, rapidly filter through sandy soils, unless a sufficient quantity of marl or lime has been previously applied to the land."* On heavy soils lime also promotes fertility, but it is probable that its action takes place in a different manner. Hence the necessity of recognising the class of soil on which a particular manure may be employed with advantage, and the expediency of combining geological knowledge with chemical investigation.

W. Smith in speaking of this subject says, "The strata succeed each other in a certain order and being delineated, a knowledge of the strata becomes the natural and safe foundation of improvement, and if agricultural chemistry be ever successfully applied

* Journ. Roy. Agric. Soc., xiv., p. 813.

to the practical purposes of agriculture, it must be by proceeding with the chemical analysis of soils along the range of each stratum."* The practical advantages to agriculture to be derived from an accurate and detailed geological survey may be classed under three heads:—

1. Where lime and other manures are most required.
2. Where grass may be laid down with advantage, and what fields are most suitable for particular kinds of crops.
3. Where to form plantations, and where the strata exist that are most suitable to the different class of trees.

For this reason a knowledge of the geology of the country is of great importance in estimating the value of the land. The truth of this was long ago recognised, even when the first principals of geology were scarcely understood, and when maps on the present large scale were not thought of. Thus, in 1683, soil maps arranged according to the main geological divisions were proposed by Lister, and in the Report for the Board of Agriculture (1794) there is a small map by J. Tuke in which the North Riding is divided into the five following districts:—

Tabular Hills, Hambleton Hills, Howardian Hills	Limestone soil.
North Moorland	Greetstone.
Vales of York and Pickering	Variety of soils.
Vale of York	Sandy soil.
Cleveland and the coast district	Clayey soil.

In 1818, Marshall published a small map of the northern counties in which the main distinctions in the strata are noted and their outcrop roughly indicated. The most noteworthy case however where the principles of geology have been applied to an agricultural survey is that of Hackness, where, in 1830, W. Smith, who was for many years land-steward to Sir J. Johnstone, made a geological map of the estate on a large scale, and drew up an account of the strata, in which he pointed out that "the value of each field corresponded to the variations of the strata, and were limited by the areas which these occupied on the surface."† This map and memoir we shall refer to at greater length in treating of the Hackness district (see pages 482 and 507).

Although there are many circumstances, such as deposits of boulder-clay, gravel, alluvium, the growth of peat, the accumulation of talus, and the tendency on sloping ground of a higher bed to work over a lower one, which may modify this general law, still the main variations in the soil correspond with the principal geological divisions, and may be separated into the same general districts as were employed in describing the scenery of the country. Thus there are four great physical districts into which the area may be divided, and which it will be convenient to take separately,—that portion of the Vales of York and Cleveland which is composed of Lias Clays flanking the Oolite hills and the Chalk Wolds‡; the ranges of Moorland hills formed by the

* Journ. Roy. Agric. Soc., vol. i., p. 273.

† *Ibid.*, p. 271.

‡ In the district west of the Wolds we include the Oolites and Lias.

Lower Oolite; the Tabular hills of the Middle Oolite*; and the Vale of Pickering resting on Kimeridge Clay. The first of these forms a narrow tract to the north and west of the district, the underlying beds being the different divisions of the Lias; but the accumulation of Boulder-clay, sand, and gravel over this low ground has completely altered its general character, so that it is only in a few places that the soil partakes of the nature of a Lias clay. In the northern part of the area, including the low ground lying between the Tees and the Oolite hills, Boulder-clay predominates, while towards the rise of the hills a band of sand comes on in places, above which the ground becomes much steeper and is a mixture of Boulder-clay, Lias shale, and the sandstones of the Oolites. About Stokesley the ground is much more sandy, but south of this Boulder-clay again predominates. The soil of the greater part of the plain of Cleveland is consequently a tenaceous clay, becoming more loamy towards Stockton; this clay is very well suited for wheat or beans, in fact it forms the best corn-growing land in the district. The lower ground to the south of this is interspersed with numerous badly-drained hollows, which from their wetness and sterility give the country a peculiarly bleak and barren aspect. The Vale of Cleveland formerly possessed much more grass, and was famous for its cheese and breed of horses; but the high price obtained for corn, during the wars in the early part of the century, caused much of the land to be ploughed out, and converted into tillage; which from too severe cropping and little use of manure gradually deteriorated until it became completely exhausted.

Along the narrow tract of land west of the Oolite hills in the neighbourhood of Northallerton the Boulder-clay becomes thinner, the solid rocks below peeping through in places; consequently there is a greater diversity of soil, a narrow bank of Lias occurring along the low hill just east of the town, while the long hill just north of Borrowby forms a narrow strip of sandy land. To the east of this the rise of the ground along the foot of the Oolite hills is a mixture formed of the débris of Lias shale and Oolite sandstone, together with great quantities of sand and gravel which have been banked against them. In the neighbourhood of Thirsk the ground is again more clayey, forming cool strong lands; but as we approach the south-west corner of the Oolite hills the Boulder-clay becomes thinner, and the soil partakes more of the nature of the underlying rocks. As the Oolites have been faulted down at this corner and much broken up there is a great diversity of soil within a small area, which is further increased by numerous small patches of Boulder-clay and sand.

South of the Howardian Hills, the low range of hills along which the Lias crops out is almost completely covered by Boulder-clay with some patches of sand and gravel here and there, more particularly at Stillington, Brandsby, and Whenby. After crossing the Derwent the Lias becomes almost entirely free of Drift, and consequently the soils consist of a heavy

* In the Howardian Hills we include the Middle and Lower Oolites.

clay with little variation except where they approach the Oolite or Chalk. Along the edge of the Wolds the Lias crops out in only a very narrow strip, which usually forms a cold wet bank, that is more adapted for pasture than tillage, but is liable to be frequently modified by the talus and landslips from the Chalk above. South of Market Weighton it has rather a broader outcrop; and, as it contains thin bands of limestone, forms a somewhat stony soil, which is considered to be some of the best arable land in the neighbourhood.* About Houghton the character of this ground is entirely altered by a thick covering of blown sand, which is only fit for woods and plantations when the roots of the trees can penetrate to the clay. This light soil is often improved by marling with the Lias clay below, so that land which was formerly covered with ling and furze was in 1848 worth 20*s.* an acre.† Between North Cave and the Humber the Lias sinks beneath the sandy alluvium of the plain, and the Oolitic rocks above form a range of low hills over which, from the thinness of the different beds, the soil is very variable; being sandy and calcareous over the Oolite, very sandy over the Kellaways Rock,‡ and very stiff along the narrow band of Kimeridge Clay at the foot of the Chalk. In this neighbourhood many of the farms are situated along the Wold foot, and consequently comprise a portion of each of the several divisions of the strata which run in narrow bands parallel with that escarpment. For this reason the soil on these farms is very varied, but may be classified in the following three divisions:—

1. The Chalk Wolds.	Friable soil, arable.
2. The Oolites -	Band of Kimeridge Clay, all in grass. Deep rich loam resting on gravel. Light sandy loam resting on the Kellaways Rock and the Inferior Oolite limestone. Loam and sand along the base of the Oolite escarpment.
3. The alluvial -	Arable and grass.

From Brantingham southwards the ground is covered by a thick deposit of sand, by which it is rendered more uniform but much impoverished.

The second district, which comprises the Cleveland Hills and the moorlands to the south, is formed by the outcrop of the estuarine and marine beds of the Lower Oolite. These consist principally of thick beds of sandstone of various degrees of hardness, interstratified with bands of shale, which form a great spread of cold barren moorlands little suited for the purposes of agriculture. The soil is thin and of a very inferior quality, many of the hills are covered with loose blocks of stone, and on several there is a thick growth of peat. This latter is, however, generally

* There is a full account of the agricultural geology of this district by Thorp, Proc. Yorksh., Geol. Soc., vol. i., p. 207.

† In some cases 100 to 150 cubic yards per acre have been thus spread, and in no case has it been found advisable to apply less than 80 yards per acre. Legard, Journ. Roy. Agric. Soc., 1848, vol. ix., p. 92.

‡ This soil is said by Thorp to be even more sandy than that of the Inferior Oolite, which contains 97 per cent. Loc. cit., p. 215.

confined to the hollows and "slack" places, where small springs issue, and which are often clothed with rushes, moss, grass, &c. Along the watershed dividing the Esk and Derwent drainage there are many peat bogs, some of which are of considerable size, and abound with the remains of trees principally birch; the largest of these are near the Falcon Inn on Harwood-dale Moor and May Moss on Allerston High Moor, besides which there are smaller patches at Fen Bogs near Goathland, on Egton Moor, and at the head of Kildale. There are also several peat-filled hollows on the moors north of the Esk valley.

Although this is the general character of the area it is considerably modified from two causes, which render certain portions more suitable for cultivation. These are, firstly, the thick deposit of Drift, which covers the northern portion of these hills, and the district along the coast; and, secondly, the deep valleys which cut through the Oolites into the Lias below forming well-cultivated regions among the desolate moorlands of the southern part. The greater part of the area that lies north of the valley of the Esk is covered with Boulder-clay and sands, which run up from the coast to a height of from 600 to 850 feet. This has rendered the eastern slope of these hills more fertile than it would otherwise have been, and enabled it to be enclosed and cultivated; while the western and southern part is left in its primitive state of moorland. Over the eastern part, from the alternations of clay and sand and also from the solid strata often appearing through the Drift, the soil is very variable; but the ground is too exposed ever to be of much value for cultivation, although the deep narrow valleys which intersect the country are well suited for the growth of woodlands. The woods about Whorlton, Ingleby, Kildale, Guisbrough, Wilton, Upleatham, Kilton, and Rousby afford the prettiest scenery in Cleveland; while the beauty of the Esk valley is enhanced by woods along its sides, particularly Arnecliffe, the Murk Esk, Little Beck, Cock Mill, and Larpool.

South of the Esk the Lower Oolites form a range of barren moorland, which in places rises to a great altitude and constitutes the wildest and most inhospitable part of the whole district. Over these moors the subsoil is generally sand, which in some places is formed into a "pan" or crust cemented together by ferruginous matter, which is impervious to water and has to be broken up before the ground can be brought into cultivation. The greater part of these moorlands therefore being not worth reclaiming is devoted to sheep runs. The sandy land in the less exposed situations may be utilized for turnips, oats, and potatoes, but the stronger land although it will grow grass for a few years, nevertheless, in the course of time, reverts to its original heather. As this land costs about 20*l.* an acre to reclaim, and then will only let for about 12*s.* 6*d.* an acre, which does not represent much interest on the outlay, there is not much inducement to bring it into cultivation.* The more sheltered parts might no doubt be rendered profitable as plantations; but before that

* Coleman, Report of the Roy. Comm. on Agric., 1881, p. 151.

could be done it would be absolutely necessary that the ground should be thoroughly drained. The general infertility of this region is, however, broken by the numerous deep valleys by which it is intersected; and which, being well sheltered by the lofty hills that surround them, are enclosed and cultivated, and able to support a scattered population. Many of these were among the earliest districts to be enclosed, and were chosen as sites for monastic establishments, the remains of which are numerous in these secluded valleys.

Along the sea-coast south of Whitby the solid strata are also covered by glacial beds over a narrow strip from one to three miles in breadth, which, in the lower ground at Robin Hood's Bay, Staintondale, Cloughton, and Scarborough, attain a considerable thickness, and form a variable soil, usually clay, but sometimes sand or gravel. The effect of this covering upon the cultivation of the land is most marked; the extent of the enclosures following very closely the limit of these beds. Along the whole extent of this narrow tract of country the best land is that near the coast; while it gradually gets wet and strong as it approaches the moors. The great drawback to successful planting, or in fact to any form of cultivation throughout this region, is its situation exposed to the full force of easterly winds*; and its liability, during the early summer, to sea fogs, when crops further inland are able to enjoy the full benefit of sunshine. That the sea air is unfavourable to plantations is evinced by the stunted appearance of the trees along the coast: but in the more sheltered situations, as at Mulgrave and Hayburn Wyke, they appear to thrive, and are a great addition to the beauty of the coast scenery, which would be otherwise very bleak and bare. On the Mulgrave estate, comprising 8,600 acres, there are 1,200 of wood, chiefly of sycamore and alder near the sea, and oak, &c. inland.

The third district includes the three ranges of hills which encircle the Vale of Pickering; the Tabular Hills in the north, the Hambleton Hills in the west, and the Howardian Hills in the south. These are composed of the sandstones and limestones of the Middle Oolites, although in the latter district the beds are so thin that it is more convenient to include the Lower Oolites as well. The Tabular Hills, which extend from the coast at Scarborough to the valley of the Rye above Helmsley, form a lofty table-land, terminating in a steep escarpment to the north and along the sides of the numerous valleys that intersect the range, but having a gentle slope to the south towards the Vale of Pickering. Along the northern edge of this district the Lower Calcareous Grit crops out, forming a dry but infertile soil, which is generally moorland; but as the ground slopes towards the south, more calcareous beds come on, and it is enclosed and cultivated. The moors formed of the Calcareous Grit are said to be entirely devoid of calcareous matter, while the upper portion of the limestone contains as much as 93 per cent. of carbonate of

* As an instance of the power of the wind on these moors we may mention that many of the trees which were growing on the escarpment of Rievaulx Moor were some years ago torn up by the roots and hurled on to the top of the plateau.

lime and a half per cent. of iron, the remainder being clay and silica in nearly equal proportions. As we approach the Vale of Pickering, thick beds of limestone crop out, which render the ground very productive; and in fact, where the soil is deep and mixed with "redstone," it forms some of the best corn-growing land of the district. Although the fertility of the soil over these hills gradually improves from the north to the south, the general regularity is interrupted by the thick beds of sandstone which alternate with the limestone; and it consequently becomes arenaceous or calcareous accordingly as it is situated on the various divisions of the strata indicated on the geological map. The influence of the underlying rock upon the soil and vegetation is very marked in some places. This is particularly the case upon Dalby Warren, where a thin bed of limestone is intercalated between two sandstones; the calcareous soil of the former is covered by grass or bracken, while the arenaceous soil of the latter is always clothed with heather. The junction between the two is so sharp, and the contrast of colour between the green herbage and brown moorlands so striking, that the divisions of the strata, which run in parallel bands along the hillsides, can be followed by the eye at some distance. This part of the district, from the porous nature of the rocks, is very dry, and has been extensively occupied as rabbit warrens, which cover an area in this part of the country of over 6,000 acres. In former times a large trade was carried on in these skins, which were sold to the hatters of the neighbouring towns. The rabbits were caught in a shallow pit or trap provided with a swing board over which they must pass in going from one field to another, or in entering small enclosures erected for the purpose, called "types," in which turnips or other food was placed.

The northern escarpment of the Tabular Hills, and the sides of the intersecting valleys, being too steep for cultivation, are usually left in moorland or utilized for plantations. It is within this district, forming a part of the Tabular range of the Middle Oolites, that the Hackness estate is situated, which, as we have mentioned, was so scientifically surveyed by W. Smith. The influence of the underlying rocks upon the soil is here very marked, and Mr. Smith, from his knowledge of the strata, soon recognised the connexion between the two, and drew up a report, which is a model of what an estate survey should be. This report, which, apart from its scientific value as an accurate survey of the Hackness Hills, is of much interest as a memorial of the veteran geologist, we give in the Appendix. Sir J. Johnstone, in alluding to this survey, says, "When on descending the hillsides it was found that there were certain fields which, whether towards the north or south, whatever the aspect, whatever the local circumstances, invariably produced good wheat, it was a triumph for agricultural geology to discover that these fields were invariably upon the Oxford Clay, or rather where the lower beds of the Calcareous Grit become mixed with that formation."* Coleman

* Journ. Roy. Agric. Soc., vol. i., p. 271.

gives the following particulars of the Hackness estate*:—25 per cent. is arable, 22 per cent. is pasture, 40 per cent. are moors, and 13 per cent. are woods; the average rent of which is 21s., divided as follows:—limestone, 20*s.*; sand of the Kellaways Rock, 30*s.*; Oxford Clay, 20*s.*; peat, nil; clayey loam, 35*s.* 6*d.* to 50*s.*

The Hambleton Hills are very similar in character to those just described, with the exception that the strata are on the whole more sandy; and, most of the area being very lofty, it is not so suited for cultivation. Nevertheless a considerable part of the ground is enclosed, and forms good arable land, the great barren spreads of the Calcareous Grit being turned to profitable account as plantations. Many of these are of comparatively modern date, some, for instance, as near the Hambleton Hotel and on Wykeham Low Moor, since the Ordnance Survey was completed; but there are also still a few places where the natural woods remain, this is the case along some of the branches of the Rye and other secluded valleys.

In the Howardian Hills the several divisions of the Lower and Middle Oolite are so thin that the breadth of their outcrop is very limited, and consequently there is a great variety in the character of the soil. On the whole calcareous and arenaceous rocks prevail, so that the soil is with few exceptions rather light. Between Gilling and Malton the Coralline Oolite occupies the northern slope of the hills and forms the best corn land. South of this the Calcareous Grit and Oxford Clay form a steep bank which is principally covered by woods. The rest of the ground is occupied, by the Lower Oolites, which are here very arenaceous, and produce a poorish soil that is frequently uncultivated. A good deal of the land in Newburgh Park and Grimston Moor south of Gilling was some time ago broken up and cultivated, the sandy ground being said to answer extremely well for potatoes and oats. The country about here, from the great variety of strata, is undulating and broken; and forms one of the prettiest districts in N.E. Yorkshire. For this reason it has been chosen as the site of numerous residences surrounded by parks which stretch almost continuously from Coxwold to Malton.

The fourth and remaining area comprises the Vale of Pickering. This great valley, which is scooped out of the Kimeridge Clay, has over its eastern portion been covered by so great a thickness of glacial beds and alluvium that the character of the ground is entirely altered; and consequently there is a considerable difference in the soil at the two ends of the vale.† Thus at the west end, where the superficial beds are thinner, the Kimeridge Clay rises up through the alluvium in numerous hillocks forming, where not covered by gravel, a heavy clay soil. At the foot of these hills there is usually a rich sandy loam, although the soil of this flat land varies from a coarse gravel to a stiff alluvial clay. Over the eastern half of the valley the soil is, on the whole, much inferior; this arises principally from the land lying very low,

* Report of the Roy. Comm. on Agric., 1881, p. 149.

† Marshall separated this valley into two districts, "the mudland quarter in the west, the marshland quarter in the east." Review and Abstract of the County Report of the Board of Agriculture, vol. i., p. 428. 1818.

and being difficult to drain; in consequence of which it is largely covered with marshes and carrs. The margin of the vale often consists of a sound deep loam, very productive of corn or herbage, but it varies considerably in different parts; thus about Allerston and Kirkby Moorside, where the Kimeridge Clay rises above the alluvium, the land is very heavy and is mostly left in permanent pasture; while on the opposite side of the valley, along the foot of the Howardian Hills and thence eastwards beneath the escarpment of the Wolds, it is very light, particularly about West Heslerton, where the fields are covered with blowing sand, possibly the remains of a shore when this valley was either a lake or an estuary. At the eastern end of the vale between Hunmanby and Filey there is a considerable area of Boulder Clay which forms a very tenacious clay, except in a few places where beds of sand and gravel cause the land to be somewhat lighter. Along the margin of the larger rivers such as the Derwent, the Rye and one or two others, there is usually some breadth of rich alluvial soil brought down by the streams, which is often extraordinarily fertile.* This alluvium is sometimes at a higher level than the surrounding country; for instance the Derwent after it debouches from the gorge at Ayton flows on the top of a ridge formed of its own deposits, which overlap the peaty carrs on either side, thereby much improving these infertile soils. Previous to the improvements effected in the drainage by cutting the artificial course between Filey and Yedingham, and by diverting the waters north of the Forge Valley direct to the sea, the Vale of Pickering was mainly covered with marshes and meres, which gave their names to numerous places; many of these are mentioned in Domesday, but are now unknown with the exception of Seamer.† The drainage of this district was commenced under the powers of an Act called "The Muston and Yedingham Drainage Act" which was passed in 1800. By this means great improvement was effected over the eastern portion of the valley; but the drainage of the western end still requires to be undertaken, as well as the removal of obstructions lower down the river. The Rye and its tributaries, which rise in the higher moorlands, during a wet season bring down vast quantities of water; which, being unable to get away by the existing channel, flows over the surface, and causes extensive floods resulting in great injury to the low grounds about Salton and other places.

Besides the character of the different soils that occur in the district the nature of the climate is equally important from an agricultural point of view; and this is to some extent influenced by the geological structure. The eastern part of Yorkshire is, from the ground standing at a less elevation, considerably drier than the western part of the county, and for the same reason the rainfall over the eastern part of the Jurassic district is much less

* The soil of Ryedale is said to be so rich that it will bear a crop of oats seven years successively. Young's Hist. of Whitby, p. 802.

† Odulfesmere, Chiluesmares, Aschilesmares, Maxudesmares, Chigogesmers. See Bawdwen's Domesday, p. 11, also Young's History of Whitby, pp. 885, 886.

than over its western and central moorlands. The summer season in this part of Yorkshire is said to be three weeks behind that of the southern provinces. A region composed of hills and valleys, of sea-coast and inland districts must necessarily experience a great variety of climate.* The hills are bleak and cold, the valleys warm and sheltered; but its proximity to the sea renders the general temperature more uniform than at places further inland. The easterly winds coming direct off the sea are not so dry; nor the westerly winds, having parted with a great portion of their moisture in crossing the higher ground in the western part of the county, so wet, as is the case in many parts of England. During the spring and summer months vegetation is much retarded by the easterly winds†, which bring up a cold fog off the sea, that is not dispersed till it has passed some distance inland.

The elevation of the ground above the sea has also a great effect upon the cultivation of crops, as grain sown upon high land has not time to ripen before the approach of winter. The greatest height at which corn can be grown in this district is stated to be about 600 feet above sea-level; and as the greater part of the Oolites from the Tabular range of hills northwards are above this elevation, it is only in the valleys and along the sea-coast that cultivation can be carried on. The southern slope of these hills, flanking the Vale of Pickering, is however both from its situation, and the rich character of some of the soil, much more favourable for agricultural purposes, although it is a curious fact that the crops grown on these southern slopes are a week later than those about Malton. The reason of this is not very apparent, but it has been suggested that the numerous cold springs which burst out of the rock at the foot of the hills may be the cause of this difference in the two sides of the valley.

Each of the above districts to a certain extent pursues a different system of agriculture, thus on the Lias and a portion of the Oolite "the two crop and fallow" is the course generally adopted in Cleveland; while in the Vale of York, 1, turnips; 2, barley; 3, seeds; 4, wheat, is more usual. On the Oolites the course of husbandry is, 1, turnips; 2, oats; 3, 4, seeds: 5, oats; but in the Vale of Pickering it is more varied, it being the custom in some cases to sow seeds once in eight years, and to take two white straw crops after seeds; in others the seeds are left down for three years, and then oats and wheat are the usual rotation.

Water Supply.

The question of water supply in modern times is one of great importance, especially in the neighbourhood of large centres of population, where the necessity of procuring pure water is yearly assuming greater proportions. In a district like the present, however, which has no very large towns, and which is composed of Oolitic rocks that are noted for their power of absorbing water and furnishing numerous and copious springs, the difficulty is not so much felt. Nevertheless even here the springs or wells in the

* The climate of the moorlands is said to be several degrees of latitude colder than the Vale of Pickering.

† These during the summer months are not true easterly winds, but local inward currents caused by the greater heating of the atmosphere over the land.

immediate neighbourhood of the towns are not always sufficient, and it is necessary to have recourse to other sources.

Considering how largely water enters into our daily comsumption, and how necessary it is for health that it should be pure and uncontaminated by sewage or animal matter, it is very essential to know where the best supplies are to be found, and how they may be most easily made available. In prosecuting an inquiry of this sort an accurate knowledge of the geology of the district is absolutely necessary if we are to avoid the mistakes and consequent loss of money which often occur.

The amount and disposition of the water beneath the surface is dependent upon the nature and structure of the rocks. These, as is well known, are composed of alternations of pervious and impervious beds; which either retain the water, or allow it to pass in certain directions, giving rise to the numerous springs with which these hills abound. Rain falling on the surface percolates through the porous beds, such as sandstones; or is conveyed by cracks and fissures till it meets an impervious stratum, such as shale; where it either collects, or is thrown out in the form of springs. The amount of water that sinks into the ground in this country in a district composed of nearly an equal extent of permeable and impermeable strata has been estimated to be about a third of the entire rainfall, the other two-thirds being either lost in evaporation or passing direct to the streams. Consequently the amount of rain falling in a district is an essential item in estimating the quantity of water that may be contained in the rocks. Over the north-eastern part of Yorkshire the rainfall appears to vary from about 26 inches in the low ground to 36 inches in the centre of the hills (Danby, &c.;) but owing to much of the district being thinly populated there are not sufficient observations to make a very reliable estimate. The average annual rainfall in the places named is as follows*:—

Place.	Observer.	Height above Sea (feet).	Rainfall (inches).
Yarm	J. Hull	80	26·66
Whitby	M. Simpson	184	26·92
York	H. Richardson	60	26·93
Malton	H. Hurtley	75	28·69
Pocklington	J. Coxon	230	31·76

There is also another circumstance which affects the water supply. This is what has been called the capacity of rocks for water. All rocks to a greater or less extent absorb water, a portion of which is held back by capillary attraction, while the remainder passes more or less freely through the strata. The water which is thus retained has been called by Prof. Prestwich "the water of imbibition";† it varies considerably in different classes of rock, and is consequently another important factor in estimating the amount to be deducted from the ascertained rainfall. In the present case we have not attempted to thoroughly

* Rainfall tables of the British Isles for 1866 to 1880 by G. J. Symons. 1883.

† Prestwich's Geology, vol. i., p. 156.

work out either of these subjects; they are questions which require careful and accurate observations spread over a number of years; we therefore only draw attention to what are essential points to be considered in making an accurate calculation of the amount of water that the strata could afford.

Where a permeable stratum overlies an impermeable one, and is more or less surrounded by deep valleys, as is the case in the outliers and headlands formed by the Calcareous Grit and many of the Oolitic sandstones, the water sinks down till it meets the impervious shale where it rests. When these sandstones become sufficiently saturated to allow of its overflowing the water oozes out along their outcrop, or, if confined to definite channels, gives rise to the springs we find along the sides of the hill. Owing to the retardation which water experiences in passing through the strata, the amount retained near the centre of the hill is greater than at the outskirts; and consequently the upper limit of the completely saturated rocks, from which water may be drawn, forms a low arch or rather dome, as shown in the following diagram:—

FIG. 26.

[. *Section across the Hackness outlier.* S.

)iagram showing the position of the permeable and impermeable strata, with their le of saturation; and illustrating the different positions of springs throughout the)ular Hills.

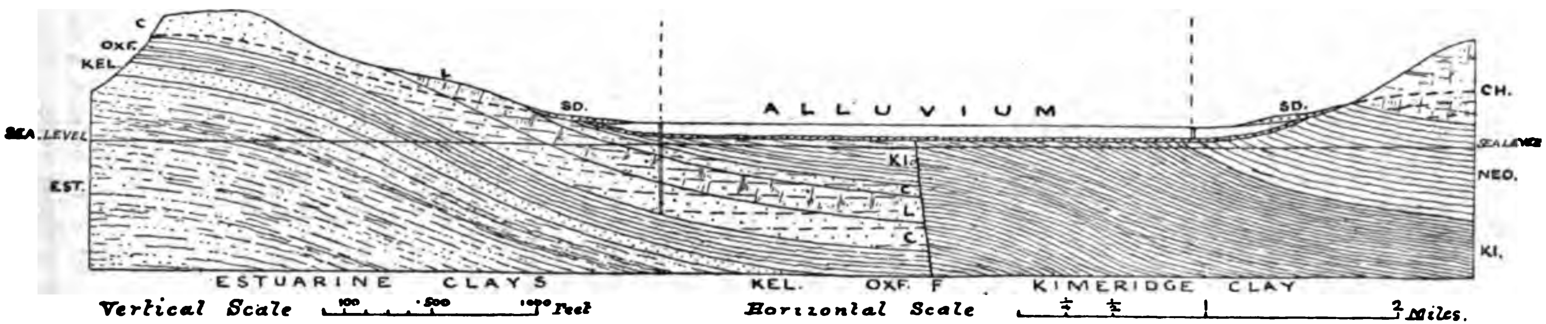
:. Calcareous Grit. O. Oxford Clay. K. Kellaways Rock. E. Estuarine Shales. 'he dotted line shows the mean limit of saturation.

This is the reason why wells sunk near the edge of an escarpment are never so reliable, nor the supply of water so permanent, as those made in other positions. For the same reason it is some time after a wet season before the water reaches the level of complete saturation; and consequently the winter rains often do not affect the level of water in wells till late in the summer. It is in this manner that a permanent supply is kept up, both in our deeper wells and more powerful springs, and that rivers are able to continue their flow during long continued droughts.

When a permeable stratum dips beneath an impermeable one the conditions are rather different. In this case the rain falling on the surface enters at the outcrop of the permeable rock and is carried down beneath the impermeable stratum where it accumulates; and, from there being no escape for the water, until its upper level reaches the outcrop of the impermeable bed, often attains great pressure. When these upper strata are pierced the water springs to the surface with more or less force giving rise to what are known as artesian wells. In this district this is the condition which prevails over a great part of the Vale of Pickering, and has caused it to be such a valuable reservoir both of natural springs and artificial wells.

FIG. 27.

Section across the eastern portion of the Vale of Pickering.



Vertical Scale, Six inches to a Mile; 880 feet to an inch. Horizontal Scale, one inch to a Mile.
Diagram to illustrate the arrangement of the water-bearing strata and the different positions of the artesian wells.

SD. Sandy Drift.
CH. White Chalk.
NEO. Neocomian Clay.
KI. Kimeridge Clay.
C. Calcareous Grit.
OXF. Oxford Clay.
KEL. Kellaways Rock.
EST. Estuarine Shale and Sandstones.

I. The relative position of the Irton artesian well.
G. The relative position of one of the numerous artesian wells sunk at the railway stations and farm-houses throughout this valley.
F. The approximate position of the great Pickering-Brompton fault.

The broken lines crossing the bedding of the strata indicate the position of the saturated rock.

Under these two conditions the underground water supply exists, although its general behaviour is usually complicated by many local circumstances.

Water in its passage through the strata takes up a number of substances, particularly lime, iron, and magnesia, in combination with carbonic acid, chlorine, and sulphur; which, according to the amount and character of the salts contained, render it more or less hard, and give rise to mineral springs or "spas" as they are called. Thus water flowing over a clay district is soft, whereas on limestone it is hard; and from the same cause water collected at the surface in catchment reservoirs is softer than that obtained from wells. For this reason it is most essential that we should ascertain clearly from whence the water has its source, and the strata through which it percolates, as some springs are detrimental by their hardness either for commercial use or for domestic purposes; this is particularly the case in districts composed of calcareous strata, where the water, even if it is not injurious for drinking, will probably be very destructive to steam boilers. A considerable amount of organic matter is also taken up by the water in its passage through the soil. This however is speedily got rid of by filtration through the porous strata; the injurious nitrogenous principles, becoming oxidized, give rise to acids, which unite with the alkalies of the soil, forming harmless compounds of soda and potash.

In studying the rocks of this district in relation to their water bearing capabilities it will be observed that there are four principal horizons of permeable rocks, along the outcrop of which rain will be collected; and, according to the lie and position of these beds, with respect to the impermeable strata, will a greater or less amount of water be given out in springs or retained in the rock for the supply of wells.

The uppermost of these strata is the Chalk, which forms the southern boundary of the Jurassic rocks along the eastern portion of the Vale of Pickering; and which also overlies the long strip of these beds between Malton and the Humber. This rock is noted for its power of absorbing water; and on account of its greater thickness probably contains a larger supply than any other bed in this part of the county. Owing to the south-easterly dip of the strata, however, the greater part of the water contained in the Chalk is carried away from the district with which we are now more immediately concerned. Still a large amount is thrown out by the underlying clays both along the northern and western escarpments, although it may be considered small when compared with the enormous volumes discharged by this rock on the eastern side, at Driffield and elsewhere. On the south side of the Vale of Pickering and along the Wold-foot from Malton southwards the springs are the principal source of supply; although, when water is required at some distance from the fountain-head, wells are sunk, generally in superficial beds, but occasionally in the solid strata, Lias or Oolite as the case may be.

The next group of strata, which has the greatest capability of absorbing water and furnishing powerful springs, is the Corallian Series, taking the term in its largest sense to include all the sandstones and limestones between the Oxford and Kimeridge Clays. This series of rocks is eminently porous, quite equalling the Chalk in its power of absorption, and like that formation furnishing springs; which are only less in extent, so far as the outcrop of the rock or gathering area is less. These rocks extend from the coast at Scarborough to the Hambleton Hills, and thence curve round to the east in a narrow strip along the south side of the Vale of Pickering till they are lost beneath the Chalk Wolds near Malton.

The outcrop of these beds covers an area of about 175 square miles; and supposing the average annual rainfall to equal 30 inches,* only one third of which is absorbed by the strata, they alone would furnish a supply of about 25,000,000,000 gallons.† That the amount absorbed by these rocks is very large is proved by the numerous and copious springs which burst out where they are in contact with the Kimeridge Clay, and also to a less degree along their outer escarpment.

In the Tabular Hills the dip of these beds being towards the south the majority of the water is conveyed in that direction towards the Vale of Pickering. Along the northern edge of this valley there is a large east and west fault which has thrown down the Kimeridge Clay against the several divisions of the Corallian Series. The consequence of this is that the water, percolating through these latter, is checked by this wall of impervious shales; behind which it accumulates, till it is thrown out in the great springs at Howkeld Head,‡ Keld Head, Brompton, and other places. East of Brompton, from the line of fault leaving the foot of the hills and the Kimeridge Clay resting regularly on the upper part of the Corallian Rocks, the water sinks beneath the former formation; where, being dammed up by the fault to the south, it accumulates under some pressure; and the conditions exist which are favourable for the construction of artesian wells. It is in this area, at Irton, that the boring was made for the supply of Scarborough; and it is also from this group of rocks that the other supplies of water for that town are drawn. It will therefore be as well before proceeding further to give a rather more detailed account of these springs.§

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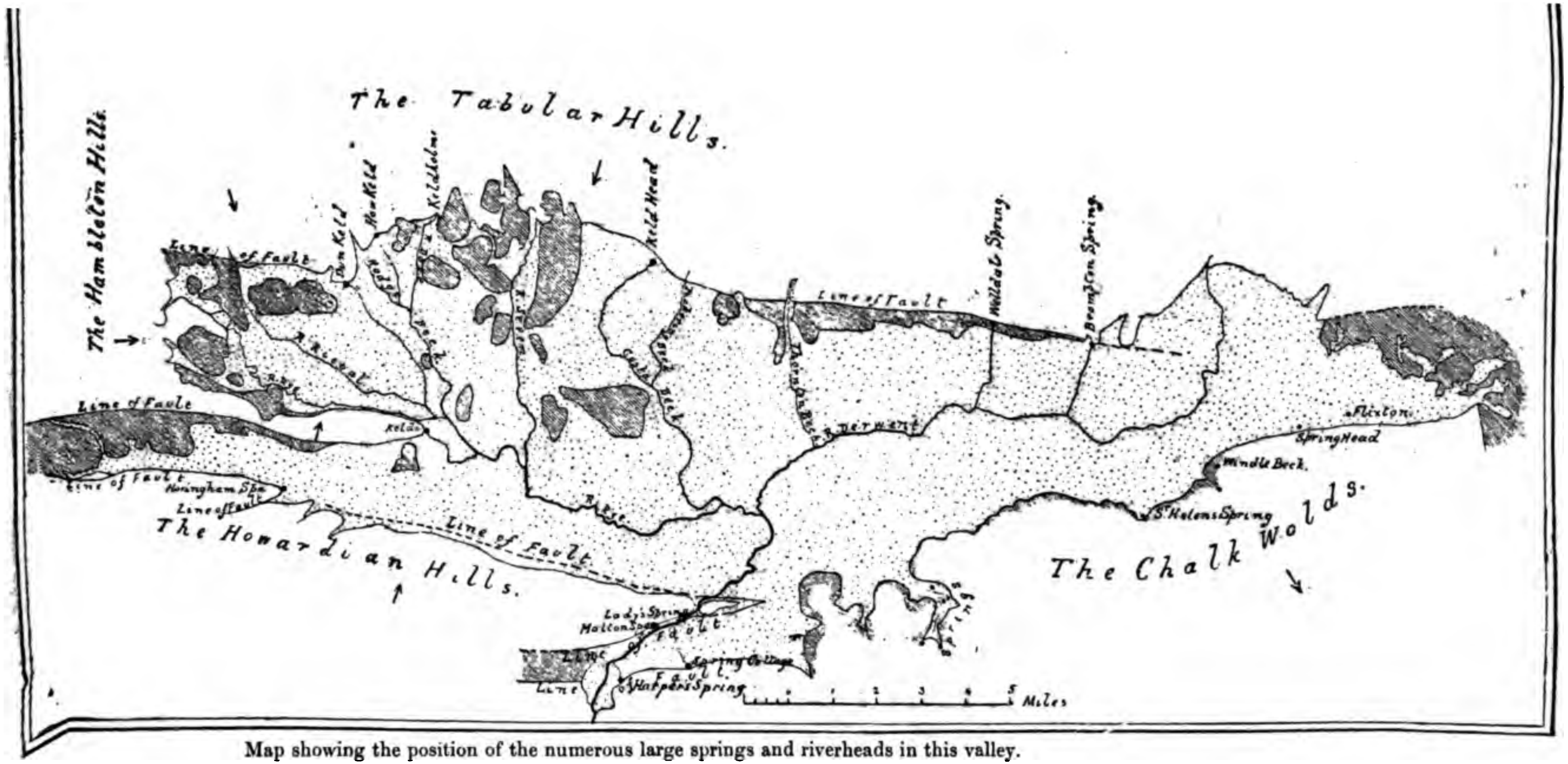
* This estimate at first sight may seem rather too much, but it must be remembered that the principal gathering ground for these rocks is the higher part of the district, where the rainfall would be greater than at the comparatively low-level recording stations.

† "One inch of rainfall equals 1 gallon, falling over 2 square feet, or 22,427 gallons per acre, or 14,355,280 gallons per square mile. Such a rainfall spread over a year of 365 days, gives a daily average of 62 gallons per day per acre, or 40,000 gallons per day per square mile." De Rance, The Water Supply of England and Wales, 1882, p. 18; also Proc. Geol. Soc. Yorksh., 1889, p. 211.

‡ Howkeldhead signifies "deep spring head." Young and Bird, loc. cit., p. 211.

§ I am indebted to Mr. Millhouse, the Engineer of the Waterworks, for many of the particulars given below.



Map showing the position of the numerous large springs and riverheads in this valley.

Important springs thus •.
Pervious rocks (Oolite and Chalk) } Plain.
Impervious rocks (Kimeridge Clay) } Shaded.

Alluvium of the vale (Sands, Clay and Gravel) } Dotted.

The arrows show the general inclination of the strata.

Scarborough is at present supplied from three sources, all of which issue from the Corallian Rocks. The first of these to be brought into use was the large natural spring in Cayton Bay; which discharges at the rate of about a million gallons per day, and was previous to 1845 employed in driving a mill. This water issues from the lower part of the Calcareous Grit, where it is brought by a large fault against the impervious beds of the Oxford Clay. The site of this spring is consequently the natural outlet for all the rain absorbed on the high ground between here and Deep Dale, and probably a portion also of that falling on the southern end of Weaponness Rigg if not of the ground beyond.

This source however being found insufficient for the increasing population of Scarborough, a well was sunk in 1870 at Osgodby through the Coral Rag and Calcareous Grit into which headways were driven for a total length of 70 yards. This well is situated to the south-west of Cayton Bay and draws its water from the same part of the strata as that spring. It is moreover nearly on the same line of strike as this spring; and it is a curious fact, tending to show the large amount of water contained in these rocks, and the extreme slowness with which it percolates through them, that pumping at Osgodby does not affect the Cayton spring.* The pump here which is able to raise 864,000 gallons per day can exhaust this well in dry seasons, but not in wet; the average rate of flow into this well, however, cannot be estimated, as it is a curious fact that the surface water only rises to 90 feet above Ordnance Datum in the wettest times, showing an overflow or escape to exist underground at that level. In 1882 these two sources were further supplemented by boring at Irton; where, as we have mentioned, the Corallian Rocks dip below the Kimeridge Clay, the conditions being favourable for artesian wells, and consequently a very fine spring was obtained, the water from which has sufficient pressure to rise 10 feet above the surface. This boring penetrates the superficial beds, the Kimeridge Clay, and the whole of the Corallian Series, being carried down to a depth of 428 feet, the last 28 feet of which is in the upper part of the Oxford Clay. The diameter of the bore varies from 12 to 24 inches, from which the water is discharged at the average rate of a million gallons per day. It is an interesting fact connected with this borehole that the level of the water in it is affected when the water is let off from the mill dam at Ayton, and also when certain swallow holes at the side of the river Derwent just north of the village are dammed up. This has lately been proved from experiments made by the Engineer of the Waterworks; when by temporarily damming up these swallow holes it was found that all the wells in the village except one or two became dry in a few minutes, and by keeping the water out of the rock for the space of 14 days or so a very wide area was affected, the marshy ground between Ayton and Irton became dry, and the wells in these villages and beyond lost water. The ordinary level of the

* The greater acceleration of the flow at Cayton may be caused by the joints and fissures here having become more open through constant wear.

water in the Irton well, however, was only lowered 10 feet, although the pumping went on as usual, thus showing that the water here is partly conveyed along fissures in the underlying rock and is kept up by the Kimeridge Clay, which is banked against the foot of the hill.

The Irton water, like all springs from the Corallian Rocks, is very pure although somewhat hard, as will be seen from the subjoined analyses. The gathering ground from which this well is supplied is very extensive, and probably includes the whole of that part of the Tabular hills situated south of the great escarpment between Seamer and the anticlinal axis north of Allerston, an area equal to from 25 to 30 square miles; a large feeder is also derived from the river Derwent, as has been proved from the observations mentioned above.

The following analyses show the character of the Scarborough water, and the slight difference there is between the three respective sources. The two analyses from Irton show a slight difference; the first of these is from a trial-boring only 100 feet deep.

*Analyses of Scarborough Water.**

—	Cayton Spring, 1875.	Osgodby Well, 1885.	Irton, Boring, 1879.	Irton Well, Sept. 21, 1885.	Irton Well, Aug. 26, 1890.
	Grains per gallon.	Grains per gallon.	Grains per gallon.	Grains per gallon.	Grain per gallon.
Total solid residue dried at 212° F.	23·00	22·00	17·0	15·7	15·88
Chlorine	3·80	2·20	2·0	1·55	1·50
Nitrogen as Nitrites	none	none	—	none	none
Nitrogen as Nitrates	about 0·5	·335	—	0·78	·065
Oxygen absorbed in 2 minutes at 80° F.	—	none	—	0·011	·008
Oxygen absorbed in 4 hours at 80° F.	—	·033	—	·024	·03
Phosphoric acid	—	merest trace	—	none	none
	Parts per million.	Parts per million.	Parts per million.	Parts per million.	Parts per million.
Free Ammonia	none	·0064	·04	·0054	·008
Albumenoid Ammonia	0·04	·005	·036	·004	·062
	Degrees of Clarke's Scale.	Degrees of Clarke's Scale.	Degrees of Clarke's Scale.	Degrees of Clarke's Scale.	Degrees of Clarke's Scale.
Temporary Hardness (removed by boiling).	11·0	11·2	10·5	10·6	9·6
Permanent Hardness (unaffected by boiling).	5·0	5·0	4·1	4·4	4·3
Total Hardness	16·0	16·2	16·6	15·0	13·9
Alkalinity expressed as Carbonate of Lime.	—	10·7	—	9·7	10·5
Solid residue consists of:—					
Silicia	—	·56	—	·21	·5
Oxide of Iron and Alumina	—	·36	—	traces	·66
Carbonate of Lime	—	8·27	—	8·93	9·36
Sulphate of Lime	—	3·41	—	2·17	1·29
Nitrate of Lime	—	1·96	—	·45	·38
Carbonate of Magnesia	—	2·58	—	1·37	1·22
Chloride of Sodium	—	3·62	—	2·55	2·47
Minor constituents and loss	—	1·24	—	·02	—
	—	22·00	—	15·70	15·88

* The first of these analyses is by J. Attfield, the others are by J. Baynes, jr.; that for 1879 was supplied by Mr. Filliter, the others by Mr. Millhouse, the engineer of the works.

Before leaving the water supply of Scarborough, we may notice the means adopted for this purpose, in olden times, before the springs in the Corallian Series were turned to profitable account. This subject is of some interest to geologists from the fact that it gives a page in the life of William Smith who was called in as consulting engineer. We have therefore given in the Appendix a detailed account of this scheme from the Scarborough Souvenir which was written from notes supplied by Smith himself.* The springs recommended by Smith were those issuing from the Estuarine Series below the outlier of Kellaways Rock known as Spring Hill, the water from which was dammed up in the joints of the rocks until required, thus making in a very original manner a reservoir of winter water for summer use.

Although the Tabular Hills possess such a magnificent supply of underground water, very little use was made of it in former times, except from natural springs. Thus along that part of the slope of these hills between the valleys of the Rye and the Dove, except quite the highest ground, the farms and villages are supplied by artificial watercourses, often constructed at great trouble and expense, which wind round the sides of the hills similar to the "levadas" of Madeira. These watercourses are in some cases over 10 miles in length, and convey the comparatively soft water from the high moorlands to the north to the farms situated on the slope of the hills above Helmsley and Kirkby Moorside. Some of these are of great antiquity, that to the north of Helmsley having been made by the monks of Rievaulx, and that above Kirkby Moorside about the middle of the eighteenth century.†

In the Hambleton Hills the Corallian Series forms a lofty tableland having only a slight amount of dip. The surface is therefore almost entirely composed of pervious beds which terminate, except in one short space, in bold escarpments that are cut down to the Oxford Clay below. The consequence of this is that water is readily absorbed, and equally readily given off, springs being very numerous, but none of so great volume as those previously mentioned, except at the extreme end of Caukless Bank, where these beds appear to sink regularly beneath the Kimeridge Clay, and the water collected over this long promontory is forced out in a spring similar to those on the north side of the Vale of Pickering. At Salton, which is a little over a mile from this spring, a boring has been carried down a depth of 316 feet through the Kimeridge Clay, and taps this water which is here found to be slightly sulphureous, probably from contact with the overlying pyritous shales.

In the Howardian Hills, from the outcrop of the Corallian Series being much narrower, the gathering area is more limited, and consequently there are but few springs of any magnitude. The large fault which ranges along the northern edge of these

* See Appendix 2. Also Phil. Mag., ser. 2, vol. i., p. 415.

† Analyses of several springs in the neighbourhood of Helmsley are given by Dr. R. Bruce Low, who discusses their influence on the health of the district, in a paper on "the Etiology of Endemic Goitre." Brit. Med. Journ., Jan. 14 and 21, 1882.

hills no doubt throws out a considerable amount of water, but the springs themselves are masked by a thick covering of superficial beds. At Malton, however, towards which these rocks decline and where they are enclosed between large faults,* the water is enabled to collect in considerable quantity, and to form the copious spring (the Lady's Well) which supplies that town. The following analyses of the Malton water have been published :—

Analyses of Malton Water, by T. Fairley.

——	Reservoir.	Lady's Well.	Barnby's Yard.†
	Grains per gallon.	Grains per gallon.	Grains per gallon.
1. Chlorides, equal to common salt - -	2·87	2·46	3·28
2. Nitrates of Lime - - - -	2·21	3·12	6 11
Sulphates and Carbonates of Lime and Magnesia.	13·54	14·44	13·53
Silica, Oxide of Iron. Alumina - -	traces	traces	traces
3. Volatile and Organic Matter - -	3·84	0·98	1·68
Total dissolved solids - -	19·46	21·00	24·60
1. Containing Chlorine - - -	1·74	1·49	1·98
2. „ Nitric Acid - - -	1·70	2·40	4·70
Corresponding to oxidized Ammonia -	0·46	0·648	1·27
3. Containing Ammonia - - -	0·0022	0·0008	0·002
„ also Organic Matter - -	0·0028	0·0033	0·0047
Corresponding to nitrogenous organic matter about.	0·028	0·033	0·047

This supply not being considered adequate either in quantity or quality, it has lately been proposed to impound the water coming from the numerous springs in Nine Spring Dale near North Grimston which issue from the junction between the Oolite clays and the base of the Chalk at the rate of 398,500 gallons in 24 hours.‡ The analysis of this water compared with that at Malton is given below.

Analyses of Water from Nine Spring Dale and Malton, by J. Baynes.

——	Nine Spring Dale.	Lady's Spring.	——
Total solid residue - -	15·60	27·80	Grains per gallon.
Chlorine - - - -	1·10	1·05	Grains per gallon.
Free Ammonia - - -	·0368	·0054	Parts per million.
Albumenoid Ammonia - -	·0230	·0160	Parts per million.
Temporary Hardness - -	11·25	14·80	Degrees (Clark).
Permanent Hardness - -	4·16	4·85	Degrees (Clark.).
Total Hardness - -	15·41	19·65	Degrees (Clark).

* For the structure of the rocks here see Horizontal Sections of the Geological Survey, sheet 139.

† This is from a private well in the town and shows the difference between well water and the natural spring. The reservoir is the water pumped from the spring at Lady's Well.

‡ The above particulars which were taken in Dec. 1889 have been supplied by Messrs. Fairbank and Son, C.E.

The Kellaways Rock forms the third horizon of permeable rocks. This bed, although very porous, only occasionally comes to the surface over any considerable area; consequently it cannot be expected to supply more than a limited amount of water, notwithstanding that a certain quantity may be conveyed into it by means of joints from the overlying strata. It usually crops out in a narrow bank at the foot of the Tabular escarpment, but on Allerston High Moor and about Newton Dale it forms a larger spread, and consequently to the south of these points probably contains the largest amount of water. The junction of the Kellaways Rock with the underlying clays is very sharp and regular; so that the water issuing from the rock forms a row of small springs or a line of verdure, that is very noticeable even in moorland districts. The Kellaways Rock, from the limited extent of its outcrop, and from the great depth at which it lies where covered by other beds, has not been made much use of as a water-bearing stratum; but there are no doubt many situations where, if the sites for wells were judiciously selected, this bed would afford an efficient supply.

The Lower Oolites constitute the fourth area into which it is convenient to divide the water-bearing strata of the district. These are composed of frequent alternations of pervious and impervious beds, which are very irregular both as to their thickness and occurrence; so that no rule, as to the water-bearing capabilities of the strata, can be laid down, that are applicable to all parts of the area; but in judging of them the local peculiarities of each district must be taken into consideration.

In a general way the most pervious beds of this group of rocks are the Moor Grit and the thick sandstones towards the base of the formation, as well as the fossiliferous grit of the Grey Limestone Series over that part of the district where this rock occurs. These cover a greater or less extent of ground in different parts, and give rise to numerous springs, but none of very large volume. The largest amount of water is probably retained in the thick sandstones overlying the Lias at the base of the series; and it is into these beds that wells might be sunk with the greatest probability of success; but in all cases regard must of course be had for local circumstances. We repeat again that this is a district in which, from the very irregular and lenticular character of the beds, no general rules can be laid down, but that each case must be judged on its own merits.

The following analyses of waters occurring in a district where these rocks crop out help to give some idea of the class of water that may be expected to be obtained in this area. The first and third are from springs in the Moor Grit; the second from one in the Boulder Clay a slight distance over that bed; the fourth from a boring in the Lower Oolites beneath a thick covering of Boulder Clay.

Analyses of Water from Cloughton and Scalby, by Prof. J. Attfield.

—	Cloughton Newlands.	Scalby Bridge Mill.
	Grains per gallon.	Grains per gallon.
Total solid matter, dried at 212° Faht.	14·00	27·00
Ammoniacal matter yielding 10 per cent. Nitrogen (equal to Ammonia per million nearly 0·02 and 0·05).	0·01	0·03
Albumenoid organic matter yielding 10 per cent. Nitrogen (equal to Ammonia per million nearly 0·02 and 0·035).	0·01	0.02
Nitrites	none	none
Nitrates, containing 17 per cent. of Nitrogen (equal to grains of Nitrogen per gallon 0·05 and 0·04).	0·3	0·25
Chlorides, containing 60 per cent. of Chlorine (equal to grains of Chlorine per gallon 2·7 and 3·2).	4·5	5·3
Hardness, reckoned as Chalk "grains or degrees"—		
removed by ebullition	6·	7·
unaffected "	4·	7·
Total Hardness	10·	14·

Analysis of "Marshall's Slack Spring," Scalby Water Company, by A. Voelcker.

	Grains.
Organic matter and loss (including oxidizable organic matter ·112)	2·31
Oxide of Iron	traces
Carbonate of Lime	10·38
Sulphate of Lime	1·46
Nitrate of Lime	·13
Carbonate of Magnesia	·65
Chloride of Sodium	3·62
Soluble Silica	·35
	18·70

*Analysis of Water from a Boring at the Grand Hotel, Scarborough.**

Total solid impurity	39·78
Organic Carbon	·041
Organic Nitrogen	·008
Ammonia	·010
Nitrogen as Nitrates or Nitrites	0
Total combined Nitrogen	·009
Previous sewage contamination	·590
Chlorine	3·70
Temporary Hardness	16·1
Permanent "	3·6
Total "	19·7

* From the Sixth Report of the Rivers Pollution Commission, 1874, p. 98.

There are two or three other borings in Scarborough also sunk into these rocks, but we are not aware that the water has been analysed. We give below three analyses taken from Jugger Howe Beck, the east branch of the Derwent, on Fylingdales Moor, at a time when it was proposed to impound this water for the supply of Scarborough*; as it shows the character of water that may be expected to be obtained from catchment reservoirs situated on the moors where the Estuarine sandstones and shales crop out.

Analysis of Water from Jugger Howe Beck (Filtered), by J. Baynes, Jr., April 1879.

Total solid residue (212° F.)	7·	grains per gallon.
Chlorine	1·5	,, ,,
Total Hardness	4·0	degrees.
Permanent Hardness	3·75	,,
Free Ammonia	·013	parts per million.
Albumenoid Ammonia	·076	,, ,,
Nitrogen as Nitrites	None.	

Another Sample of the same, by Prof. Attfield, May 1879.

	Grains per gallon.
Total solid matter, dried at 212° F.	12·
Ammoniacal matter yielding 10 per cent. Nitrogen	0·01
Albumenoid organic matter yielding 10 per cent. Nitrogen	0·04
Nitrites	none
Nitrates, containing 17 per cent. of Nitrogen	none
Chlorides, containing 60 per cent. of Chlorine	2·5
Hardness (reckoned as Chalk, grains or degrees) removed on boiling	4·
Unaffected by ebullition	5·
Total Hardness	9·

Another Sample of the same, by Prof. Tidy, May 1879.

Total solid matter	9·10	grains.
Ammonia	trace.	
Nitrogen as Nitrates and Nitrites, Nitric Acid	trace.	
Oxygen required to oxidize the Organic Matter	0·076	grains.
Organic Carbon	0·214	parts per 100,000
Organic Nitrogen	0·020	parts per 100,000
Lime (CaO)	1·79	grains.
Magnesia (MgO)	0·612	,,
Sulphuric Anhydride (SO_3)	0·080	,,
Chlorine	1·512	,,
Common Salt	2·478	,,
Hardness, before boiling	3·3	degrees.
,, after boiling	3·3	,,

The Lias, from its consisting almost entirely of a thick series of impervious shales, is essentially a non-waterbearing stratum; and, were it not for the great quantity of glacial sands and

* This water was rejected on account of its softness and consequent action on lead.

gravel which frequently overlies the shales, the region where these beds outcrop, would be but badly supplied with water.* A little may be absorbed where the sandy beds of the Middle Lias are of any thickness, but the outcrop of these beds is so limited and so often covered by Boulder Clay that it can scarcely be said to influence the water supply of the district. When however these beds are pierced at some distance from the outcrop, or where they are overlaid by the Oolites, the accumulation of water is much greater. For instance, in Kilton Pit the water is said to enter at the rate of 1,000 gallons a minute; and in the North Skelton Shaft the enormous amount of 3,000 gallons a minute has been encountered.†

The superficial beds, composed of alternations of sand, gravel, and clay, are capable of affording small supplies of water; but the relative position of these beds is so very irregular, that no reliance can be placed upon obtaining water at a particular spot. These beds however only cover a small portion of the area along the sea coast, the lower part of Cleveland, the Vale of York and the Vale of Pickering. Over the latter a great part of [illegible] beds are probably of Post-glacial date, and rest partly [illegible] Kimeridge Clay and partly on Boulder Clay; so that a [illegible] shaped hollow exists, which is filled in with these newer clays [illegible] such a manner that the water soaking in along the edge [illegible] vale is carried between the two beds of clay, where it is [illegible] at considerable pressure. When this upper clay is bored [illegible] it gives rise to artesian wells, the supply from which is of [illegible] force to reach the top of the houses. Many of the [illegible] stations and farmhouses between Knapton and [illegible] plied in this manner by borings of small diameter and [illegible] ...h 100 feet or more in depth. The relative position [illegible] ...ate waterbearing horizons that exist in the Vale of [illegible] ...t to shown in the diagram on page 488. [illegible] North

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* Water from the Lias formation [illegible] inferior; the solid impurities being [illegible] grains per gallon.—De Rance, The [illegible] p. 41.

† Further analyses of waters [illegible] Appendix.

‡ Sixth Report of the Rivers [illegible] cit., p. 63.

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Redcar	—	2,458	Springs, excellent	61,459
Filey	652	2,337	Springs, reservoir	—
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Mineral Springs.

There are several springs of this class which issue from the Jurassic rocks, but at the present time none of them attract much attention, although the sites of some are still chosen as summer resorts. In former days many of these were held in considerable estimation for their curative properties, and gave rise to a somewhat copious literature, developing in the case of Scarborough to a paper warfare between Drs. Simpson, Wittie, and Tonstall.* The springs which may be classed under this head are those at Hovingham, Scarborough, Whitby, Malton, Filey, Guisbrough, Kildale, Riccaldale, Sleightholmedale, Newtondale, Kepwick, and several others. Of these the springs at Hovingham and Scarborough are the only ones that are at all patronized at the present time.

The Hovingham springs issue from a piece of boggy ground about a mile west of the village, and are situated just at the junction of the large fault which bounds the Howardian Hills and the branch fault which comes down the valley between Hovingham High Wood and Cawton. It would therefore appear that it is the intersection of these faults at this point which has given rise to these springs, and caused them to be so strongly impregnated with mineral salts.

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Analyses of the Spa Wells, Scarborough, by Prof. E. Frankland, March 1889.

—	Grains per Gallon.	
	North Well.	South Well.
Carbonate of Lime	43·02	33·60
Carbonate of Magnesia	3·90	1·72
Carbonate of Iron	1·22	1·01
Sulphate of Lime	76·87	86·09
Sulphate of Magnesia	98·55	69·57
Chloride of Magnesium	2 35	3·48
Chloride of Potassium	1·30	1·37
Chloride of Sodium	21·83	23·77
Silica	1·26	1·12

"The water of both wells is of high organic purity. It is rich in saline constituents, and belongs to the class of saline chalybeate mineral waters. The iron contained in the water is equivalent to 1·87 grains per gallon as bicarbonate ($C_2O_6H_2Fe$) in the North Well, and to 1·55 grains per gallon in the South Well."

It is a curious fact that in the older analyses given of these springs the sulphate of magnesia in the South Well is stated to be more than half as much again as that in the North Well. Whether this is owing to incorrect analyses in former times or whether the condition of the water has changed is doubtful; but if both analyses are fairly correct it would appear that the supply of this salt is becoming exhausted, and that the value of these springs as mineral waters is gradually declining. In former times the water of the South Well was considered to be a mild aperient, while the North Well, which has little or no aperient power, is

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According to Young similar springs to those at Scarborough are found at Upgang, nearly a mile west of Whitby, and in Larpool Wood.† The former of these, which was at one time renowned in song, has now been buried up, and almost lost from the washing away of the cliff.

The Malton Spa issues on the line of the large fault on the south side of the town in some gardens at the side of the river Derwent. This spring is stated by Dr. Short to be very similar to that at Scarborough, but there does not appear to have been an accurate analysis made of the water. It is a strong saline chalybeate, and possesses considerable purging and diuretic qualities. An imperial gallon yields 225 grains of solid constituents, consisting of sulphate of magnesia, sulphate of lime, common salt, and a portion of protoxide of iron. The water which flows at the rate of 13 gallons an hour is clear when it issues from the ground; but a scum soon collects on the surface.‡ The rate of flow is not altered by the season, and consequently the source of the spring must be deep seated. Dr. Short considered that there was no medicinal water stronger than that at Malton, and he laments the fact that it was not more appreciated in his day.

The Spa at Filey is situated near the summit of the North Cliff just at the western end of the Carr Nase. It is believed to have been the site of an old Roman villa, coins, pottery, and other remains having been found at the spot. The water, which is stated to have a constant flow of 8 gallons an hour, is rather strongly impregnated with salts of considerable medicinal value; and is said to be useful in dyspepsia. It contains a small quantity of iron and traces of iodine and bromine besides the following constituents§:—

* Dr. Granville states that the rate of flow is different in the two wells; that of the south spring being at the rate of half a pint in 20 sec., whereas that of the north spring is half a pint in 7 sec. or 765 gallons in 24 hours. Loc. cit., p. 163. Dr. Short gives the rate of flow as 120 gallons per hour. Mr. Goodricke informs me that, at the present time, the rate of flow is, North Well, 32 gallons per hour, South Well, 18 gallons per hour; but the water does not run quite so fast as this in summer.

† Young's History of Whitby, p. 787.

‡ Dr. Travers' report quoted by Dr. Granville, "Spas of England," Northern Spas, p. 149. See also Dr. Simpson, "Treatise on the Malton Spa, 1669"; Short's History of Mineral Waters, pp. 196–210; Eastmead, Historia Rievallensis, p. 362.

§ West, loc. cit., p. 111. In the History and Antiquities of Filey, by J. Cole, the solid contents are given as 360 grains in the imperial gallon.

	Grains per gallon.
Sulphate of magnesia	48·96
Chloride of magnesium	36·40
Chloride of calcium	41·20
Chloride of sodium	210·80
Carbonate of soda	58·08
Total	395·44

The spring apparently issues from the Boulder Clay, and may derive its salts partly from that formation in the same manner as has been suggested in the case of the Scarborough Spa.

At Spa Wood to the east of Guisbrough there is a sulphur spring of some note, which was discovered by the Rev. James Wilcocks in 1822. It issues from the shales of the Upper Lias which, as is well known, contain large quantities of sulphate of iron. This spring has been much neglected, although the water is stated to be an invaluable remedy for diseases of the digestive organs, and also an admirable tonic. The following is the analysis given by Goodwill, an apothecary at Lofthouse, and quoted by Dr. Granville in his Spas of England.*

Analysis of Guisbrough Spa, by Goodwill, 1823.

	Grains per gallon.
Carbonate of soda	15·44
Muriate of lime	5·20
Sulphate of lime	0·80
Carbonate of magnesia	1·04
Pure alumina	2·00
Pure silica	2·40
Oxide of iron and carbon	3·20
	Cubic inches
Sulphuretted hydrogen gas	0·96
Free carbonic acid gas	6·00
Temperature 50½ Fahr.	

In Kildale there is another sulphur spring which issues from the Whinstone dyke where it crosses that valley. The dyke here is in contact with the Upper Lias shales, and contains a considerable amount of pyrites, from which the sulphuretted hydrogen in the water is probably derived.

At the west end of Cliff Ridge there is a spring called Chapel Well which also issues from the dyke, and which in olden times was supposed to possess miraculous powers.†

At Crosby Cote there are two wells sunk about 5 feet in blue shale, the water from which is strongly impregnated with sulphuretted hydrogen. The following are the analyses of these waters‡:—

* Loc. cit., p. 227 and table; also Ord's History of Cleveland, p. 207.

† An account of the superstitions relating to this spring and to others at Roseberry Topping, and near Kettleness, is given in Young's Hist. of Whitby, p. 883. See also Brand's Pop. Antiquities II., p. 267, and Graves' Hist. of Cleveland, p. 221.

‡ From Mr. A. G. Cameron's account in Memoirs of the Geological Survey, Explanation of 96 N.W., p. 15.

Analyses of Water, Crosby Cote, near Northallerton.

—	Well in the Courtyard.	Well in the Park, south of the House.
	Grains per gallon.	Grains per gallon.
Solid matter, chiefly carbonate and sulphate of lime.	66·50	38·15
Chlorine (equal to grains of Chloride of Sodium per gallon 12·04 and 4·06).	7·28	2·89
Nitrogen as Ammonia - - -	·0065	·0014
" as Albuminoid - - -	·0014	·0196
" as Nitrates - - -	·0044	·1900
Hardness. - - - -	31 degrees	22·7 degrees.
Hardness after boiling - - -	24 "	11·1· "

There is also a spring near Kilton Mill which Young states "contains carbonate of lime, sulphate of lime, a small portion of muriate of soda, with carbonic acid gas, and sulpheretted hydrogen gas."*

In Riccal Dale there is a very copious spring which, from the large amount of matter deposited around the sides of the basin from which it issues, appears to be strongly impregnated with mineral salts. The water has an inky taste and is apparently an ordinary chalybeate, but it has not attracted much attention probably on account of it being in a thinly populated district and not near any path or road. This spring issues from the Upper Estuarine Series, and its mineral qualities may be derived from the Grey Limestone which is a short distance below. There is also a spring, apparently of the same character, situated in the next valley to the east, known as Sleightholmedale Spa, which rises at about the same geological horizon.

Besides the above there are several springs which from the large amount of calcareous matter they contain may be considered as mineral springs. One of these is situated in Newtondale near the sharp bend in that valley just below the curious hole in the rock known as the Needle Eye. This, which is what is called a petrifying spring, issues from the base of the Kellaways Rock and Cornbrash; from which formations it receives the large amount of lime that is deposited as calcareous tufa over the hillside below.† Other springs of this class exist at many places, the most noteworthy being at Kepwick; at Ebberston; in Forge Valley; in Troutsdale; St. Wilfred's Well at Wildon Grange near Coxwold; in Kilton Beck; at Wilton Castle; and in Coatbank Wood near Egton. It was at one time proposed to use the springs at the former of these places for the supply of Thirsk,

* Loc. cit., p. 787.

† This water is also chalybeate. There was formerly a bath here, and an annual Sunday fair is said to have been held at this place.

although the hardness of most of them varies from 6 to 8 degrees, while one is stated to be as much as 25 degrees.* The following is an analysis of one of these petrifying springs flowing into Gill Beck, and situated just above the enclosed land:—

Analysis of Spring at Kepwick.

Chlorides, equal to chloride of sodium	1·65
Sulphate of lime	10·17
Carbonates of lime and magnesia	13·45
Silica	trace.
Oxide of iron and alumina	traces.
Volatile and organic matter	0·28
	25·55

The water contains much free carbonic acid.

To the south of Thirkleby there is a chalybeate spring, which issues from a borehole that was put down close to the large fault which bounds the Oolite here on the north side, and which is probably the cause of this mineral water.

Besides the above the following chalybeate springs are mentioned in Young's History of Whitby,†—in the alum works at Eskdaleside and Littlebeck; at the upper end of Maybecks; in Wheeldale Beck; a spring called Fryup Trough; at Gerrick Hole near Wapley; also at Middleton, at Nether Normanby,‡ and at Cropton near Pickering.

Sites of Villages, &c.

Before closing this chapter we may notice the manner in which the presence of the most copious springs of pure water has determined the sites of the villages and the chief centres of population. Thus along the foot of the hills surrounding the Vale of Pickering, where we have noticed that the finest springs of water burst out, villages are very numerous; while over the rest of the valley, except in the neighbourhood of beds of gravel, there are only a few scattered hamlets and isolated farm houses, many of which are now supplied by artesian wells, but in former times had only the "beck" water to depend upon. The same is the case in other parts of the district, the villages and even single houses being mostly arranged along the principal escarpments in the neighbourhood of the larger springs. In the Cleveland district, from the large quantity of Boulder Clay covering the ground, the springs are more scattered; and consequently the principal sites of population do not follow so rigidly the outcrop of the solid strata. The great commercial industry in this region

* Thirsk is now supplied from a catchment reservoir in Lunshaw Beck on Boltby Moor. The water from here has a hardness of 3·6, of which 3·5 is permanent.

† Loc. cit., p. 788.

‡ This is a strong sulphur spring; see Dr. Short, p. 299.

There are two or three other borings in Scarborough also sunk into these rocks, but we are not aware that the water has been analysed. We give below three analyses taken from Jugger Howe Beck, the east branch of the Derwent, on Fylingdales Moor, at a time when it was proposed to impound this water for the supply of Scarborough*; as it shows the character of water that may be expected to be obtained from catchment reservoirs situated on the moors where the Estuarine sandstones and shales crop out.

Analysis of Water from Jugger Howe Beck (Filtered), by J. Baynes, Jr., April 1879.

Total solid residue (212° F.)	7·	grains per gallon.
Chlorine	1·5	,, ,,
Total Hardness	4·0	degrees.
Permanent Hardness	3·75	,,
Free Ammonia	·013	parts per million.
Albumenoid Ammonia	·076	,, ,,
Nitrogen as Nitrites	None.	

Another Sample of the same, by Prof. Attfield, May 1879.

	Grains per gallon.
Total solid matter, dried at 212° F.	12·
Ammoniacal matter yielding 10 per cent. Nitrogen	0·01
Albumenoid organic matter yielding 10 per cent. Nitrogen	0·04
Nitrites	none
Nitrates, containing 17 per cent. of Nitrogen	none
Chlorides, containing 60 per cent. of Chlorine	2·5
Hardness (reckoned as Chalk, grains or degrees) removed on boiling	4·
Unaffected by ebullition	5·
Total Hardness	9·

Another Sample of the same, by Prof. Tidy, May 1879.

Total solid matter	9·10	grains.
Ammonia	trace.	
Nitrogen as Nitrates and Nitrites, Nitric Acid	trace.	
Oxygen required to oxidize the Organic Matter	0·076	grains.
Organic Carbon	0·214	parts per 100,000
Organic Nitrogen	0·020	parts per 100,000
Lime (CaO)	1·79	grains.
Magnesia (MgO)	0·612	,,
Sulphuric Anhydride (SO_3)	0·080	,,
Chlorine	1·512	,,
Common Salt	2·478	,,
Hardness, before boiling	3·3	degrees.
,, after boiling	3·3	,,

The Lias, from its consisting almost entirely of a thick series of impervious shales, is essentially a non-waterbearing stratum; and, were it not for the great quantity of glacial sands and

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With the exception of the New Red Sandstone the water derived from the Oolites is considered to be superior to that from any other geological formation; and as far as this part of the country is concerned it would appear, from experiments that have been made in the Vale of York, to be infinitely better than some obtained from that water-renowned formation. The River Pollution Commission, in describing the water derived from this group of rocks, point out that "unpolluted spring water from the Oolites is unsurpassed in its comparative freedom from all kinds of organic impurity"; and they go on to say that analysis shows "that the Oolitic rocks are not inferior to the New Red Sandstone in the energy with which they oxidize and destroy the organic matter present in the waters precolating through them."‡

* Water from the Lias formation moreover is usually considered to be very inferior; the solid impurities being stated to average as much as from 35 to 215 grains per gallon.—De Rance, The Water Supply of England and Wales, 1882, p. 41.

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‡ Sixth Report of the Rivers Pollution Commission, 1874, p. 120. De Rance, loc. cit., p. 63.

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The Malton Spa issues on the line of the large fault on the south side of the town in some gardens at the side of the river Derwent. This spring is stated by Dr. Short to be very similar to that at Scarborough, but there does not appear to have been an accurate analysis made of the water. It is a strong saline chalybeate, and possesses considerable purging and diuretic qualities. An imperial gallon yields 225 grains of solid constituents, consisting of sulphate of magnesia, sulphate of lime, common salt, and a portion of protoxide of iron. The water which flows at the rate of 13 gallons an hour is clear when it issues from the ground; but a scum soon collects on the surface.‡ The rate of flow is not altered by the season, and consequently the source of the spring must be deep seated. Dr. Short considered that there was no medicinal water stronger than that at Malton, and he laments the fact that it was not more appreciated in his day.

The Spa at Filey is situated near the summit of the North Cliff just at the western end of the Carr Nase. It is believed to have been the site of an old Roman villa, coins, pottery, and other remains having been found at the spot. The water, which is stated to have a constant flow of 8 gallons an hour, is rather strongly impregnated with salts of considerable medicinal value; and is said to be useful in dyspepsia. It contains a small quantity of iron and traces of iodine and bromine besides the following constituents§:—

* Dr. Granville states that the rate of flow is different in the two wells; that of the south spring being at the rate of half a pint in 20 sec., whereas that of the north spring is half a pint in 7 sec. or 765 gallons in 24 hours. Loc. cit., p. 168. Dr. Short gives the rate of flow as 120 gallons per hour. Mr. Goodricke informs me that, at the present time, the rate of flow is, North Well, 32 gallons per hour, South Well, 18 gallons per hour; but the water does not run quite so fast as this in summer.

† Young's History of Whitby, p. 787.

‡ Dr. Travers' report quoted by Dr. Granville, "Spas of England," Northern Spas, p. 149. See also Dr. Simpson, "Treatise on the Malton Spa, 1669"; Short's History of Mineral Waters, pp. 196–210; Eastmead, Historia Rievallensis, p. 362.

§ West, loc. cit., p. 111. In the History and Antiquities of Filey, by J. Cole, the solid contents are given as 360 grains in the imperial gallon.

	Grains per gallon.
Sulphate of magnesia	48·96
Chloride of magnesium	36·40
Chloride of calcium	41·20
Chloride of sodium	210·80
Carbonate of soda	58·08
Total	395·44

The spring apparently issues from the Boulder Clay, and may derive its salts partly from that formation in the same manner as has been suggested in the case of the Scarborough Spa.

At Spa Wood to the east of Guisbrough there is a sulphur spring of some note, which was discovered by the Rev. James Wilcocks in 1822. It issues from the shales of the Upper Lias which, as is well known, contain large quantities of sulphate of iron. This spring has been much neglected, although the water is stated to be an invaluable remedy for diseases of the digestive organs, and also an admirable tonic. The following is the analysis given by Goodwill, an apothecary at Lofthouse, and quoted by Dr. Granville in his Spas of England.*

Analysis of Guisbrough Spa, by Goodwill, 1823.

	Grains per gallon.
Carbonate of soda	15·44
Muriate of lime	5·20
Sulphate of lime	0·80
Carbonate of magnesia	1·04
Pure alumina	2·00
Pure silica	2·40
Oxide of iron and carbon	3·20
	Cubic inches
Sulphuretted hydrogen gas	0·96
Free carbonic acid gas	6·00
Temperature 50½ Fahr.	

In Kildale there is another sulphur spring which issues from the Whinstone dyke where it crosses that valley. The dyke here is in contact with the Upper Lias shales, and contains a considerable amount of pyrites, from which the sulphuretted hydrogen in the water is probably derived.

At the west end of Cliff Ridge there is a spring called Chapel Well which also issues from the dyke, and which in olden times was supposed to possess miraculous powers.†

At Crosby Cote there are two wells sunk about 5 feet in blue shale, the water from which is strongly impregnated with sulphuretted hydrogen. The following are the analyses of these waters‡:—

* Loc. cit., p. 227 and table; also Ord's History of Cleveland, p. 207.

† An account of the superstitions relating to this spring and to others at Roseberry Topping, and near Kettleness, is given in Young's Hist. of Whitby, p. 882. See also Brand's Pop. Antiquities II., p. 267, and Graves' Hist. of Cleveland, p. 221.

‡ From Mr. A. G. Cameron's account in Memoirs of the Geological Survey, Explanation of 96 N.W., p. 15.

Analyses of Water, Crosby Cote, near Northallerton.

—	Well in the Courtyard.	Well in the Park, south of the House.
	Grains per gallon.	Grains per gallon.
Solid matter, chiefly carbonate and sulphate of lime.	66·50	38·15
Chlorine (equal to grains of Chloride of Sodium per gallon 12·04 and 4·06).	7·28	2·89
Nitrogen as Ammonia - - -	·0065	·0014
" as Albuminoid - - -	·0014	·0196
" as Nitrates - - -	·0044	·1900
Hardness - - - - -	31 degrees	22·7 degrees.
Hardness after boiling - - -	24 "	11·1· "

There is also a spring near Kilton Mill which Young states "contains carbonate of lime, sulphate of lime, a small portion of muriate of soda, with carbonic acid gas, and sulpheretted hydrogen gas."*

In Riccal Dale there is a very copious spring which, from the large amount of matter deposited around the sides of the basin from which it issues, appears to be strongly impregnated with mineral salts. The water has an inky taste and is apparently an ordinary chalybeate, but it has not attracted much attention probably on account of it being in a thinly populated district and not near any path or road. This spring issues from the Upper Estuarine Series, and its mineral qualities may be derived from the Grey Limestone which is a short distance below. There is also a spring, apparently of the same character, situated in the next valley to the east, known as Sleightholmedale Spa, which rises at about the same geological horizon.

Besides the above there are several springs which from the large amount of calcareous matter they contain may be considered as mineral springs. One of these is situated in Newtondale near the sharp bend in that valley just below the curious hole in the rock known as the Needle Eye. This, which is what is called a petrifying spring, issues from the base of the Kellaways Rock and Cornbrash; from which formations it receives the large amount of lime that is deposited as calcareous tufa over the hillside below.† Other springs of this class exist at many places, the most noteworthy being at Kepwick; at Ebberston; in Forge Valley; in Troutsdale; St. Wilfred's Well at Wildon Grange near Coxwold; in Kilton Beck; at Wilton Castle; and in Coatbank Wood near Egton. It was at one time proposed to use the springs at the former of these places for the supply of Thirsk,

* Loc. cit., p. 787.

† This water is also chalybeate. There was formerly a bath here, and an annual Sunday fair is said to have been held at this place.

although the hardness of most of them varies from 6 to 8 degrees, while one is stated to be as much as 25 degrees.* The following is an analysis of one of these petrifying springs flowing into Gill Beck, and situated just above the enclosed land :—

Analysis of Spring at Kepwick.

Chlorides, equal to chloride of sodium	1·65
Sulphate of lime	10·17
Carbonates of lime and magnesia	13·45
Silica	trace.
Oxide of iron and alumina	traces.
Volatile and organic matter	0·28
	25·55

The water contains much free carbonic acid.

To the south of Thirkleby there is a chalybeate spring, which issues from a borehole that was put down close to the large fault which bounds the Oolite here on the north side, and which is probably the cause of this mineral water.

Besides the above the following chalybeate springs are mentioned in Young's History of Whitby,†—in the alum works at Eskdaleside and Littlebeck; at the upper end of Maybecks; in Wheeldale Beck; a spring called Fryup Trough; at Gerrick Hole near Wapley; also at Middleton, at Nether Normanby,‡ and at Cropton near Pickering.

Sites of Villages, &c.

Before closing this chapter we may notice the manner in which the presence of the most copious springs of pure water has determined the sites of the villages and the chief centres of population. Thus along the foot of the hills surrounding the Vale of Pickering, where we have noticed that the finest springs of water burst out, villages are very numerous; while over the rest of the valley, except in the neighbourhood of beds of gravel, there are only a few scattered hamlets and isolated farm houses, many of which are now supplied by artesian wells, but in former times had only the "beck" water to depend upon. The same is the case in other parts of the district, the villages and even single houses being mostly arranged along the principal escarpments in the neighbourhood of the larger springs. In the Cleveland district, from the large quantity of Boulder Clay covering the ground, the springs are more scattered; and consequently the principal sites of population do not follow so rigidly the outcrop of the solid strata. The great commercial industry in this region

* Thirsk is now supplied from a catchment reservoir in Lunshaw Beck on Boltby Moor. The water from here has a hardness of 3·6, of which 3·5 is permanent.

† Loc. cit., p. 788.

‡ This is a strong sulphur spring; see Dr. Short, p. 299.

has also influenced the selection of sites of population here more than the natural advantages of good water. On the whole however it is evident that the presence of springs determined the abode of the earlier inhabitants, which in course of time became the most important villages. Prof. Phillips, in writing on this district, notices this fact, and pictures the early condition of the country; we cannot do better therefore than conclude these remarks with his own words. "The country all around Malton is thus shown to have been in early times the most peopled part of Yorkshire, and so it remained till a comparatively late period. The range of villages which cling to the foot of the Wolds, from the Humber, round by Malton to Hunmanby and Filey, is remarkable; a similar crowd of large villages runs from Scarborough by Helmsley and Thirsk to the north of the Tees, and from many circumstances there is reason to conclude these lines to have been occupied by settlements in the earliest times. Along them flowed the finest springs; above them were open pastures for sheep, the bustard, the dotterel, and other birds, and below in boundless forests roamed the red deer and the wild boar; herons and wild fowl frequented the swamps; wolves, foxes, martens, and other animals of some value for skins, afforded occupation to the arrow, spear, pit, or net; while, to complete the happiness of savage life, the roving pirates or merchants of the Baltic and the Elbe might land at the 'Uchel' (Ocelum Promontorium, Flamborough), the 'Dun' (Dunsley, near Whitby), or the 'Aberach' (Eburacum, York) the coloured glass and amber which made them amulets and ornaments."*

* Prof. Phillips. The Rivers, Mountains, and Sea Coast of Yorkshire, p. 226.

APPENDIX.

1.—MEMOIR on the STRATIFICATION of the HACKNESS HILLS. By WILLIAM SMITH.

The following memoir, written in 1829 and 1830, is printed from an unpublished MS. in the possession of the late Mr. R. Turnbull, of Hackness.

Its origin is explained in the following extract from Prof. Phillip's "Memoirs of William Smith" (1844, p. 113):—

"Among the many eminent persons who at different periods of Mr. Smith's life took a lively interest in his welfare, it is the pleasing duty of his biographer to mark with grateful distinction one whose friendly regard he gained about this period, and retained during the remainder of his life, Sir John V. B. Johnstone, Bart., of Hackness. On succeeding to his estates, this enlightened gentleman was desirous of converting to practical effect on his farms some of the geological and botanical truths which he knew to have been established in the museum and the laboratory; he found in Mr. Smith the union of practical and theoretical knowledge which was necessary for his object, and a desire to exemplify that knowledge in agricultural improvements which exactly coincided with his own wishes. From 1828 to 1834 Mr. Smith acted as his land-steward, resided at Hackness, occupied himself in the usual concerns of a large landed estate, and thus passed (in the judgment of the writer) six of the calmest and happiest years of his declining life. The worthy proprietor of Hackness had hoped that the retirement, which seemed so well suited to Mr. Smith's age and taste, would have been memorable for the production of the results of a life of scientific toil, and spared neither friendly entreaty, nor pecuniary aid, nor personal exertion, to bring this favourite design to effect. Mr. Smith meditated and wrote, but did not arrange his papers, and excepting a beautiful geological map of the Hackness estate, executed in great detail and with extreme exactitude, nothing of importance came from his hands to the public."

"MEMOIR of the STRATIFICATION of HACKNESS HILLS." 1829.*

"The principal object of the annexed map is a delineation of the geological structure of some of the most irregular† ground in England, namely, that around Hackness Hall. The valleys of this district, with their intermediate

* This is the date in the original MS. It was probably commenced in that year, but not finished till 1830.

† By "irregular" Mr. Smith probably meant "varied." The stratification of these hills is noted for its great regularity, being entirely free from faults and the least disturbed of any part of the Oolites.

ridges of hills, both in form and geological construction may be considered unique. The valleys which unite about Rivaulx Abbey have the nearest resemblance; and the various branching valleys north of Locton, which comprise the Hole of Hurcomb,* are also singularly formed, but the intermediate hills are not composed of the same number of strata. Numerous other valleys in the long range of the Tabular Hills from Scarborough to Hambleton have no resemblance in form, although their geological construction, generally speaking, is the same. Troutsdale and Deepdale branch up into the moors in singular forms, and Dalby Dale above Thornton extends its ramifications by Stonesdale† almost to the edge of Crosscliff; so that the district between Newtondale and Harwood-dale, which is part of the Tabular Hills, and [is] bounded by the same kind of high contour, has the most singular valleys deeply carved into the planes of the stratification. On Knox's excellent map of the vicinity of Scarborough these forms are well depicted and may be readily compared. The form of the Hackness valleys comprised within the high land of Suffield, Silpho, and Broxa, which is geologically insular, may be compared to the branchings of a stag's horn. And no one can understand the intricate forms in the surface of the ground without traversing the hills as well as the valleys, for on riding along the high side of the elevated plain of Silpho and Broxa moors, even the ends of the valleys are not discernible.

"Such is the ground of which we have to show the geological construction, composed of insulated parts of some of the most regular strata in the British series. The highest edge of Silpho and Broxa moors, like that of all the rest of the Tabular Hills thence to Hambleton, is composed of Calcareous Grit; but this is not the highest stratum in the series, as the Coralline Limestone reposing thereon forms the points of most of the hills around Hackness Hall; and at Silpho, the lower beds of that stratum which Mr. Phillips calls the Upper Calcareous Grit, reposes on the limestone. The lowest stratum in this insular part of the stratification (which might be called 'Hackness island') is the cornbrash, and below this the alternations of sandstone and shale called the Coaly Grit‡ may be traced around the island between Silpho brows and Harwood-dale and down the Derwent, and in the line of Scalby drain§ to the cliffs at Scarborough, and is thus shown to be the base of the island, and in connexion with the high cliffs north of Scarborough and the strata which form the surface of the Moorland district.

"The series of beds in the stratification traceable by their edges around or in the island therefore consist [of]:—

1. Upper Calcareous Grit.
2. Coralline Oolite.||
3. Calcareous Grit.
4. Oxford Clay.
5. Kellaways or Hackness Rock.
6. Clay beneath.
7. Cornbrash Rock.

"Fine natural sections of all these strata, in their corresponding order of superposition, may be seen in Scarborough Castle Hill and the cliffs between Filey and the latter place.

"That geology is a science of unlimited extent and utility cannot be doubted, but while geologists choose to be mannerists rather than correct imitators of nature, some of its purposes remain unanswered. The application of this science to its most practical uses is nearly as Herculean as its establishment. Its uses in agriculture are of the utmost importance to the country, and therefore cannot be brought forward at a more convenient time than the present which calls for every stimulus to the skill and industry of the owners and occupiers

* Horcum on Ordnance Map.
† Stain Dale on Ordnance Map.
‡ The Estuarine Series (upper division) of the Geological Survey.
§ The New Cut on Ordnance Map.
|| Mapped by the Geological Survey in three divisions.

of the soil. That a knowledge of geology is the only infallible guide to determine correctly the value of land was said 30 years since by that eminent land valuer Davies,* of Wiltshire, when the principles of the science were explained to him. To know what plants are best suited to the soil a knowledge of the varieties of soil is necessary which can only be obtained by an acquaintance with their subsoils and the beds of strata upon which they rest and from which they are respectively formed. Local circumstances and casual coverings of diluvial matter may make many shades of difference in the colour of a soil, but with these allowances there certainly is no other method of obtaining such a general and practical knowledge of soils as by an acquaintance with the strata which form them and upon which they rest. There may be considerable variety and great difference in the nature of a soil when no adventitious mixture occurs, and this arises solely from a difference in the nature of the beds comprising the thick stratum from which the soil is formed. These great varieties of soil varying according to the kind of stone upon which it reposes is well known to practical farmers on the Hackness Hills, and to most other occupiers of the same kind of land thence to Hambleton. They all know there is a thin dry stony soil over the limestone, a deeper and more tenacious soil over the wallstone, nearer the moors a range of free working yellowish sand land, and poor blackish or grey sand upon the moors. The two last kinds are both of them upon the plains of the Calcareous Grit rock. The two other kinds which commonly enclose a much better soil between them are upon the stratum of Coralline Oolite, so that we have five very different kinds of land upon two strata which shows the necessity of examining the rocks in detail instead of grouping them into formations, at least it is absolutely necessary to do so in Agricultural Geology, and especially when it is to be, as in this case, locally applied to the distinctions in the rocks and soils of an estate or farm. The following is a detailed view of the strata very distinguishable in Hackness Hills:—

One formation according to Phillips.	Upper Calcerous Grit.	
	Coralline Oolite	*Limestone.*
		Spongite C-ral bed.
		Grey or Wallstone.
	Calcareous Grit	*Reddish yellow sand* corresponding with the indurated sand exposed on the north side of Scarbro' Castle Hill.
		Cherty bed of stone which forms the plains of the moors and the high well-defined edge of the Tabular Hills.
		Freestone beds below this.
	Oxford Clay.	
	Hackness Rock.	
	Clay beneath.	
	Cornbrash.	

"By laws established in geology and the help of organised fossils, the rocks in these hills are identified with the contemporaneous portions of their ranges through this island to the extent of several hundreds of miles, and as well on the continent. They are verified by localities thereof enumerated in Phillips' Geology of Yorkshire, and further by the specimens exhibited in the Scarborough, Yorkshire, and numerous other museums; and by these means philosophers are satisfied with the extent and accuracy of the science, and naturalists thus know where to collect specimens of each rock from cliffs, quarries, and other broken ground; but these broken views of the subject, which enable us to trace ranges of the respective strata from field to field and from hill to hill, and assign to each their proper limits, and so to construct geological maps on a large scale, must be sought in the visible changes which the

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* Thomas Davis of Longleat, author of the Agricultural Survey of Wiltshire, 1794. This work was re-written by his son, T. Davis, as the "General View of the Agriculture of Wiltshire," and was published by the Board of Agriculture in 1811.

different kinds of strata make on the earth's surface, such, for instance, as the principal ranges of hills and valleys, the contours of hills, swells or knolls on the sides of hills, the flatness or steepness of roads, the ranges of springs which some of the strata produce, the springs and streams, the wetness or dryness of land, and the different kinds of land turned up by the plough.

"In generalizing these and numerous other circumstances essential to the science, we are assisted by the works of art, both ancient and modern. In the earliest stages of population the dryest range of soil became a way-worn track, the shoal caused by a rock in the river a ford, and the best spring an abode. By the old method of trial and error men [found] out the richest land, and by numbers assembling for a share thereof those parts became the most populous. In modern times the same original dry track became a road, the rocky ford the best place for a bridge or a mill, and the finest spring near to dry and good land the best place for a town or village. Thus before trade and commerce had much interfered with man's agricultural employment, the greatest depth of dry good land supported a city, and the next in degree a market town, and so in gradation to the cottage. The best piece of good land in a village is commonly near the church, and that of a farm near the house. Supply and demand of food and water made the union of dry good land everywhere essential to the site of population. And although this, as at Stow-on-the-Wold and some other places, seems to have been disregarded, yet a fine spring is at no great distance below, and we find it the same at Suffield, Silpho, and Broxa, situated on the Hackness Hills; but Suffield, originally the largest place of the three, had a supply for most of the year from a pond and shallow springs from the diluvium, which also increased the depth of the soil on these rocky hills. The fine trees here and at Silpho, so much higher than the naked but less exposed hills over the Derwent, seem unaccountable until geology unravels the mystery by finding that the better soil of these heights is derived from limestone. On principles common to the sites of population it appears that the three villages are each of them situated on the best soil of all the high land. The two farmhouses on Suffield heights and Tholso* farmhouse also stand in the range of this best land, which by investigation appears to be derived from an earthy parting in the limestone rock ranging through these places, which though but thin, fortunately occupies a good breadth of surface.†

"Next to these superficial distinctions, which render this greatly elevated plain strikingly different from any other portion of the Tabular Hills, we may notice a character which it has in common with the whole range, viz., its well-edged elevated contour and the occurrence of nab ends therein, which also are common to the outline of all the singular district before noticed between Harwood-dale and Newton Dale. They are well-defined in Troutsdale; at Saltersgate [they are] conspicuous at a great distance. Some may be seen from the great road [between] Yedingham Bridge and Malton, and the singular features of more westerly points of these hills may be recognised from the walls of York.

"So extensively useful in geology is the knowledge of contours, that the great book of Nature is thereby laid open to us clear enough to read as we run.

"The detailed particulars of each stratum in Hackness Hills as they range through the fields can only be interesting to the owners and occupiers of the land. Suffice it therefore to say that the stratum composed of whitish, light blue, and blackish beds of clay above the coaly grit rock which forms the sliding cliffs of White Nab, south of Scarborough, is in Barnscliff and other places around Hackness Island similarly characterized by slips, and wet strong land, everywhere grows oaks of the best quality but is commonly over saturated with water issuing from the rocks above. There are no sites of population on this stratum nor scarcely a building unless it fortunately happens to be covered with gravel.

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* Thirlsey on Ordnance Map.

† This may refer partly to the Middle Calcareous Grit between the limestones, but it is the Coral bed at the base of the limestone that makes most of the good land near these farms as is stated in the sequel.

"The *Cornbrash* is a thin hard limestone rock, recognised only in four places around Hackness Island, at one of which in the bed of the Derwent at Langdale Bridge it became a ford. It lies near the bottom of the Hackness Rock and nowhere appears to diverge from it. It also forms a ford in a moorland beck about a mile and a half west of Lastingham, which village, like most other sites of habitation at the foot of the Tabular Hills is situated upon top of the Hackness Rock.

"Hackness Hall and the village of Everley are upon that stratum called the *Kelloways* or *Hackness Rock*, but the modern cottages at Hackness and Mowthorpe Farm are injudiciously placed below it. The by-road from Everley to Scalby Nabs follows its track to those farmhouses which stand upon it. It crosses the new road up Hey Hill at the first steep place, ranges the hill sides to Prospect House and below Comboats, diverges from the higher ranges of rocks southward round a secondary prominence and returns to and follows the road by the three Underbrow farms, and follows that by-road to William Pashby's house, which stands upon it. At this place a well 30 feet deep is sunk through the rock. Two other farmhouses on the north side of the Tabular Hills stand on nabs or projections of this rock, [one] of which more remarkable points [is] the site of Barnscliff Cottage. This seems to be the greatest elevation of the rock* from which we look down on that great wood and the Derwent rolling below at the foot of Langdale Rig, which is formed of corresponding rocks terminated by the singular conical hill of Oxford Clay, called the 'Sugar Loaf.'† Through Barnscliff the Hackness Rock traceable by its dry soil and casual protuberance comes to the junction of the roads from Broxa and Langdale-end where it slopes down with the lane to the verge of the river which in ancient times was a further inducement to ford the river upon the solid floor of the Cornbrash rock. From hence the dry soil over the Hackness rock becomes the road to Hackness. This rock skirts the cowpasture at the back of the cottages and the Inn to the rise in the road, which from the redness thereof has been called 'Red Brow' and thence through the wood by the road to the great quarry. It branches up the bottom of the valley to the great spring at the water-house, and forms so much of the brows on each side of the road to the Hall as lies below the springs. In the same manner it is traceable up Longfield valley in the beck and under the dry soil and steep banks on each side thereof to Lowdale, Highdale, and Whisperdale farmhouses. The dry soil on this rock on many accounts afforded the earliest inhabitants the most desirable sites of habitation, but most so about the church where it is deeply covered with gravel. It is everywhere near to water issuing from springs above or below the rock. Up the interior valleys the springs which are numerous flow only from the top of the rock, but about the village numerous springs issue from the bottom of the rock, and some from the top of it, and in the same manner, by the issuing of springs more or less copiously, may the bottom and top of this stratum be traced in and around the Island. Sites on this rock were also desirable, for being above the floods and alluvial soil between it and the river, and from their contiguity to the better land of the stratum of Oxford Clay lying in the slope above, while the steeper parts of the hill sides covered with wood afforded fuel and shelter and timber for constructing their houses, for it appears by the oak ribs of several old buildings now standing that they were long so constructed. The use of the valuable stone of this stratum in the construction of mansions and churches and of museums to shelter philosophers and their gleanings from Nature [was] left for more enlightened times.

"The *Oxford Clay* lying over this rock has a parallel [outcrop] all round the Island and up the sides of all the interior branching valleys forming good pastures, and where the ground is not too steep it forms some of the best wheat land. And in the low sides of the woods, where the débris of the rock above is not too thick for the tap roots of the Oak to penetrate, it grows large and good timber. The upper part of this clay becomes harder and more

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* The Kellaways Rock attains its greatest elevation, 950 feet above the sea, at High Woof How, three miles north-west of this point.

† This hill is capped by the basement-beds of the Calcareous Grit.

sandy, and finally so like the soft stone of the next incumbent stratum as to have no well-defined boundary between them.

"This soft under part of the *Calcareous Grit*, as well as the freestone over it which occurs in this rock, is always in the steep hill sides which are mostly covered with woods and modern plantations. A hard cherty bed containing fossil shells chiefly Ammonites, Terebratulæ, and Pectens forms the well edged contour of the hills and much of the poor surface of the moors which all slope inwardly towards a central depression* somewhere about Hackness Hall. On the poorest parts of the moors we discover among the short ling weather-bleached cylindrical stones an inch or more in diameter which may have been fragments of large Alcyonites. Beneath the soil lies a subsoil called 'a pan' which by its retaining water in some parts of the moors might seem to contain clay hardened by the oxide of iron.

"The Rev. Wm. Vernon in a late chemical analysis of some of these soils detected clay and decomposed basalt, probably diluvial; as in the black sand in and about the plantations pebbles of jasper, porphyry, and other hard rocks have been found. The black sand, which only skirts the better cultivated land, certainly cannot be considered as the soil of any bed in the stratification, but may have been washed off the moors.

"The *Yellow Sand* corresponding with that exposed in the north-west side of Scarborough Castle Hill, and with the same kind of sand at Newton, the Rabbit Warren at Locton, and the potato land at Sawdon, completes the varieties comprised within the mass called Calcareous Grit.

"It is the pile of beds already enumerated which composes the general range of Tabular Hills, as those superadded on the lower portions of the plain of Calcareous Grit range parallel to the Vale of Pickering to Hambleton, and are nowhere of great width except about Locton. It is remarkable that all the following superadded beds composing the pile called *Coralline Oolite* seem gradually to thicken as they decline towards the low ground, so that their terminating edges are cuneated or wedge-shaped, and therefore make no irregularities in the general slope of the hills to the south or south-east;† they preserve the same character in a curved line round the inner and lower portion of the plain of Hackness Hills; and on their dipping side in the many digitated ends of the elevated plain presented to the Hall valley they end with the abruptness common to escarpments.

"The first and lowest distinction in the beds of rock composing the thick stratum of Coralline Oolite is the *Wall Stone* or Greystone, which in shallow quarries commonly rises in flat thin pieces for fence walls. Some are good roadstone. This rock reposing on the yellow sand is covered with a deepish soil, stiff and tenacious, with few stones in it, and those generally flat and thin. It grows good crops of oats, and seems kindly for grass. The soil of this rock between Suffield and Silpho, where it is most distinguishable on the cultivated lands, seldom occupies more than one field in breadth; it seems, however, to occupy a considerable portion of the cultivated ridge between Broxa and Hackness Head.

"The *Coral Bed* is a more earthy bed reposing on the greystone, only about [6] feet containing lumps of coral and small spongites, which distinguish it from the coral over the limestone, and which has been noticed before for forming the best land about the three villages; and that on the best farms is covered with a soil so superior to the one preceding that in a pasture south of Broxa the difference in the herbage over the two rocks is easily distinguished. It forms only a small portion of soil under and just around Broxa. It occurs north and east of Silpho, mostly north and west of Tholso farm, where it produces the long piece of land called the great pasture. South-eastward it is narrowed between the ravines and moors, but widened again north of Suffield. It is considerably obscured about the village by a diluvial covering, but in its

* See Memoirs of the Geological Survey. Explanation of Quarter Sheet 95 N.W., pp. 54, 55.

† This is principally the effect of denudation and not of original deposition. The Middle Calcareous Grit is notably thicker at Silpho than it is further south above Hackness.

greatest and most regular breadth occupying many long narrow fields, it was anciently distinguished by the name of 'Suffield Ings'; and about the northernmost of the two farms in Suffield heights it forms two large and good old pastures; and the soil over this bed, which is only a parting between the wallstone and limestone of the stratum called Coralline Oolite, wherever it is in tillage, grows the best wheat. It is remarkable that most of the pools on these hills for supplying stock with water are in the range of this stratum though we cannot suspect the makers of them of knowing anything about geology. The limestone occurs in several places which we shall next describe, it forms lower ground than the preceding stratum and is about 20 feet or more in thickness, but which like the former divisions of the great rock, makes no perceptible difference in the gradually sloping surface of the hills, except in its having a thinner soil thickly strewed with fragments of limestone.

"The *Limestone* forms properly saintfoin land, but from its contiguity to the woods and the thinness of the soil in some of its banks much of it has long lain in sheep walks; burnet abounds in its herbage, which however forms a great contrast with that of the soil before described. The limestone occurs in several places, but nowhere of the full thickness of the rock, except on the hill south of Silpho, as on no other parts of the limestone can the Melania Striatus, Heddingtonesis* and the coral on the top of the rock be found. This coral lies just beneath the soil about a quarter of a mile in length but is soon covered with some of the *Upper Calcareous Grit* which on the higher part of three or four fields producing a fine loamy soil like that on the same rock on the border of the low ground in the vale of Pickering and which is there called 'Red land,' and which by good judges is considered to be the best arable land in the vale. This is the highest stratum on Hackness Hills, and from the pile of rocks which support it being of their full thickness it forms the highest interior land, but which is much below the marginal contour formed by the Calcareous Grit beneath the Coralline Oolite. Thus, by a superficial survey of the characteristic development of each stratum I have made out the ranges and width of a considerable pile of strata which have also been locally and extensively identified by their organised fossils, to which as they are arranged in the Scarborough Museum, and to the accounts published by Phillips and others, I must refer; and I may add that by the characteristic distinctions herein employed and others peculiar to the terminating edges of the different strata may geological maps of the largest scale be made of Districts, Parishes, Estates, or Farms, which by readily exhibiting the varieties of soil and inducing a better knowledge thereof would be very interesting and instructive to the owners and occupiers and generally beneficial to the agricultural interest."

October 2nd, 1830.

The map of Hackness here referred to was lithographed by Day in 1832.† The old drawing, which is still in the possession of the Turnbull family, was shown at the "Special Loan Collection of Scientific Apparatus" at South Kensington in 1877, and is thus described in the "Catalogue" (3rd Ed., p. 823):—

"William Smith's original Geological Map of Hackness Hill, Yorkshire, being one of the earliest geological maps ever constructed on a large scale.

"The maps of William Smith, 'the father of English Geology,' of the outlying mass of the Middle Oolite at Hackness, exhibit in a striking manner the great knowledge of their author, and the able manner in which he traced and mapped their geological structure, and also pointed out its bearing on the agriculture of the district. The Geological Survey Map of the same area [hung by its side in the collection], while it helps to form a comparison of the old and new style of mapping, at the same time shows that William Smith was well acquainted with the general details of this unique and somewhat obscure group of rocks."

The sub-divisions of the strata adopted by Mr. Smith in this map and memoir, compared with those employed by the Geological Survey, are shown in the following table.

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* *Phasianella striata*, Sow., and *Chemnitzia heddingtonensis*, Sow.

† There is a copy of this map in the Scarborough Museum

TABLE of STRATA near HACKNESS showing the DIVISIONS made by WILLIAM SMITH and those of the GEOLOGICAL SURVEY.

Mr. Smith's Classification.		Classification adopted by the Geological Survey.
	Upper Calcareous Grit.	Upper Calcareous Grit.
Coralline Oolite	Limestone.	Upper Limestone and Coral Rag.
		Middle Calcareous Grit.
		Lower Limestone with Coral Bed at base.
	Spongite Coral Bed.	
	Grey or Wallstone.	Passage Beds or Greystone.
Calcareous Grit	Reddish yellow sand.	Lower Calcareous Grit. (The different bands noticed, but not classed as divisions.)
	Cherty bed of stone.	
	Freestone.	
	Oxford Clay.	Oxford Clay.
	Hackness Rock.	Kellaways Rock.
	Clay.	Cornbrash with clays above.
	Cornbrash.	
	Coaly Grit.	Estuarine Series.

2.—EXTRACT from the "SCARBOROUGH SOUVENIR," 1827, containing an ACCOUNT of the MEANS adopted for supplying SCARBOROUGH with WATER. From Notes supplied by WILLIAM SMITH.*

The Reservoir in Spring Hill.

"As the practical application of knowledge acquired from geology in relation to the comforts and conveniences of man, in a most essential article of life, must be considered matter of importance, a detailed account of what may

* The Scarborough Souvenir, by J. Cole, 1827. Also Phil. Mag., ser. 2, vol. i., pp. 415-417.

be called a *geological* Reservoir of water made in the hills near Scarborough, in the dryest summer this country has experienced for sixty years, may not be unacceptable to the public.

"We know from the annual variations of springs that rocks hold a much greater quantity of water in winter than in summer; and we further know, by wet seasons, that rocks periodically hold much more than their annual average quantity both in winter and summer: and hence the question as to the possibility of retaining water in rocks for summer use is decided by the annual ana periodical operations of nature.

"For the means of altering or improving some of these natural operations, so as to render the irregular quantity of water which falls on the earth more convenient to the general purposes of man, we must resort to geology;—to find what stratum is fitting for the purpose, and what site in the range thereof, what the rock lies upon; what stratum or diluvium covers it, and the dip, rises, and troughs or undulations in the Stratum.

"The practical operations—as to levels, the supply, and mode of finding and retaining the quantity of water required depends upon the skill of a practical Geologist, Drainer, and Engineer.

"Mr. Smith had for many years contemplated the practicability of making use of rocks as subterraneous reservoirs of water, in some cases extensive enough for the use of canals; and once, in a Report on Springs, suggested such a plan to one of the Canal Companies. But for the use of Towns and dwelling-houses, many situations may be found where the joints of a rock are capacious enough for penning up winter water therein, for use in summer, and even in the dryest summers; as many springs which then fail produce a superabundant supply in winter. This was the state of the first springs, anciently taken from the adjacent hills to supply the town of Scarborough, which supply has been from time to time increased and improved at the expense of the Corporation. Within a few years new pipes have been laid at a great expense. Still, however, in the summer months, when there is much company in the town, water was deficient, and the Commissioners for improving the town undertook to search for more water in the hillsides about one mile and a half distant.

"In the month of May 1826, a small quantity was found to issue from a borehole made several years since for draining the land. On cutting an open channel up to this the discharge increased, and at the depth of 9 or 10 feet amounted to 24 hogsheads per hour. This encouraged them to proceed, and the channel under Mr. Smith's direction was deepened 4 feet, when the discharge became for some time 50 or 60 hogsheads per hour. Suspecting from an intermediate and subsequent diminution that we had drawn off a confined stock of water, and that the regular run of the spring at the end of a dry summer might not be found sufficient, he suggested the idea of damming up the produce of this spring in Winter for Summer use, as their previous supply was more than sufficient for the town in winter. The circumstances were favourable for the purpose, as there was no other known issue of water from the rock in that hill, which is about a mile long, narrow on the top, and insulated in all the upper portions of its stratification. The same rock is not opened or known anywhere else on these hillsides, but in a deep valley which separates the insular hill from the main and higher hill of Falsgrave Moor.

"In the upper end of that valley a spring was opened several years since in the same kind of rock, and with a declivity of 30 or 40 feet brought round the south end of the insular hill near to, and high enough to run into, the opening made to the new spring.

"This was sufficient to prove the general rise of the rock westerly in the base of the insular hill, and beneath an isthmus connected with the main ridge of Falsgrave Moor and Seamer Beacon. The rock in which the spring was found is a yellowish fine-grained crumbly sandstone, in thick beds, with open irony joints, the same as in the Cliff south of Scarborough Spa, and which from the quantity of carbonaceous matter it contains is here called coaly grit.*

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* Upper Estuarine Series.

"From the identification of rocks in the series above and below it, this sandstone, with its overlying and alternating clays, is analogous in position to the clay, sand, and sandstone, between the cornbrash and great oolite rocks.*

"The rock at the depth of 10 feet was found covered with regular clay about 4 feet thick; in this a mark of coal and a thin bed of hard stone full of imperfect vegetable impressions, and up to the surface a tenacious *slidden* clay. By boring through the rock, it was found to be 10 feet thick lying on clay.

"The channel, excavated up to the spring, about 30 or 40 yards long, and 15 feet deep at the upper end, was entirely in a very tenacious clay partly diluvial, with a few rounded stones in it deeply covered by slidden clay. Within 4 feet of the edge of the rock lay gravel (deeply covered also with slidden clay), consisting of large and small pebbles of whinstone, granite, mountain-limestone, which gravel, between the clay and the face of the rock, tapered downward to nothing in the bottom of the excavation.

"About 2 yards within the edge of the rock (which was nearly as upright as a wall), a basin 6 feet wide and 4 feet deep was excavated to receive the water flowing from the joints of the rock. Cast-iron pipes, branching from the main line of pipes, were laid up to this basin, to receive the regular flow of the spring, which at the end of summer was reduced to less than 6 hogsheads per hour. The clay channel, in the bottom of which the pipes were laid, was refilled with clay and puddled, so that no water could pass from the rock but through the pipes. The end of the last pipe was closed, and a vertical aperture made receiving the run of the spring.

"No further contrivance was required for stopping the water and damming it up in the rock than an open vertical pipe ground to fit tight into the aperture in the horizontal pipe; and this to the height of four feet was done by pieces of pipe, each a foot in length, tight-fitting one into another for convenience of wholly or partially damming or drawing off the stored water as occasion may require; the surplus being allowed to run in at the top of the pipe. After rainy days in the beginning of November last, those four short pieces of pipe were put in one after another, and found to dam up the water in the joints of the rock to a height of four feet, which, from the quantity wasted last summer during the progress of the works, was calculated to contain five thousand hogsheads; with the top of the vertical pipe since closed, and subsequently the main iron pipe, the whole of the water from those parts becomes forced into the cavities of the rock, and has stood through the winter from 12 to 14 feet deep, or 10 feet higher at the spring than was calculated upon penning it.

"Thus, if a depth of 4 feet gives 5,000 hogsheads—
"8 may give 10,000.
"12 feet give 15,000.

"But from temporary variations in the height, caused by water drawn off at valves placed in the pipes to cleanse them of a red sediment, and also from the quantity which ran off at different depths while opening the spring, we cannot expect the quantity in the rock to increase in proportion to the height; but if eight or ten thousand hogsheads should thence be obtained or enough to fill the great arched reservoir newly built, then, in the summer, the contents of the subterraneous reservoir, made at such a little expense, will be a great acquisition to the town of Scarborough.

"Since the last season, a Reservoir, capable of containing four thousand hogsheads, has been formed under the superintendence of that able Engineer, Mr. Smith, on the St. Thomas' grounds, and very near the site of the Church formerly dedicated to that martyr, which was totally demolished by the fire from the garrison during the siege of the Castle in the year 1644."

This reservoir was 18 feet deep, covered by a dome 40 feet span and 20 feet high; said to be the largest, so defended, at that time, in the kingdom.

* Grey Limestone Series.

ANALYSES and PARTICULARS of SPRINGS, communicated by Messrs. FAIRBANK and SON, Civil Engineers, Driffield.

—			Easingwold.			Elloughton and Brough.			Norton.	Pocklington.	
	Kirkham Abbey.	Market Weighton.	Banks Farm.	Hanover Farm.	Oulston Spring.	Upper Spring Dale.	Brough Village Pump.	Skilling Lane.	Spring Cottage.	Givendale Springs.	
—	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	—
solid residue -	29·70	26·00	22·40	22·00	26·25	18·25	78·65	239·30	26·65	18·62	Grains per gallon.
ine - -	2·50	1·30	1·10	1·23	·90	1·10	4·65	4·10	1·30	1·0296	
Ammonia -	·0426	None.	·0214	None.	None.	·0406	·1000	1·334	·0146	·00175	Parts per million.
noid Ammonia	·0540	·056	·0230	·008	·014	·0400	·1848	·470	·044	·00735	
orary Hardness	13·50°	11·00°							17·95	9·22	
anent " -	8·30°	5·00°							5·00	1·22	
" -	21·80°	16·00°							22·95	10·44	

All the above analyses are by J. Baynes, Hull, except No. 10 which is by Messrs. Broadbent and Boyce.

No. 1. Issues from behind the Hall, Kirkham Abbey, and consequently from near the base of the Lower Oolite. "A pure water but very hard. It is well fitted for drinking purposes, but will be found wasteful for washing."

No. 2. From the well of the M. W. Water Co. sunk in the Chalk close to the railway about a mile E. of M. W. The water probably issues from the junction of the Lias clays with the overlying Chalk. "A sample of water of high degree of purity."

No. 3. A spring opposite the Farm House. Probably from the Middle Lias, but through a thin covering of Boulder Clay. "A water of high degree of purity."

No. 4. From a boring in "Bog Field," about 300 yards east of Banks Farm. From the Boulder Clay overlying Lias, probably from the Middle Lias. "A water of extraordinary degree of purity." Issues from three 3-in. boreholes at the rate of 54,648 gallons per 24 hours (April 1891). This is the water selected for the supply of the town of Easingwold.

No. 5. Issues from near the base of the Lower Oolites. "A water of extraordinary degree of purity."

No. 6. Issues from the base of the Chalk overlying Kimeridge Clay. "A water of average degree of purity, and well adapted for drinking and domestice purposes."

Nos. 7 and 8. Issues from sand and gravel overlying the Cave Oolite. This water, as well as several other wells near here, is so seriously contaminated from sewage filtration as to be totally unfit for domestic purposes.

No. 9. Issues from the Coralline Oolite where it is faulted against the Kimeridge Clay. "This is a very hard water of average degree of purity." Discharges 380,000 gallons in 24 hours (Dec. 1889).

No. 10. Springs at the side of Ridings Beck near Little Givendale; issuing from the base of the Chalk at its junction with the underlying Lias clays. This water contains in addition to that mentioned above 1·68 of Nitrates, and 8·12 of Carbonates. "It is a water of excellent purity." Four of these springs yielded 106,464 gallons in 24 hours (Jan. 1891), but were stated to be exceptionally low for the time of year.

4.—WHITBY WATER SUPPLY, communicated by W. H. SINCLAIR.

Analysis by Prof. Attfield, of the Hazel Head Springs, Egton High Moor.

	Grains per gallon.
Chlorides	2·87
Ammoniacal Salts	trace.
Carbonate of Lime	7·22
Sulphate of Lime	·65
Carbonate of Magnesia	·70
Silica	·70
Organic impurity	None.
Total	12·14

Temporary Hardness	7°
Permanent ,,	2°
Total Hardness	9°

These springs issue from the Lower Oolite some distance to the south of Grosmont, and the water is conveyed in pipes to an open reservoir at Randay Mere capable of containing 12,000,000 gallons. "The water is clear and bright, is remarkably pure, has comparatively little hardness, and altogether is of excellent quality for drinking purposes, general household use, and all manufacturing operations."

INDEX.

N.B.—Names of Persons (authors, observers, and informants) are in small capitals Names of Fossils of which there are figures are in *italics*.

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